HIGH FLOW DEWATERING LITERATURE SEARCH
CONTRACT NO. DACW57-96-D-0007, TASK ORDER NO. 5

Task 2A: Annotated Bibliography of Literature Regarding High Flow Dewatering Systems

1.0 Introduction

The Portland District, U.S. Army Corps of Engineers (USACOE) has proposed a program to study, construct, and evaluate surface collection and bypass systems at Bonneville Dam to improve outmigrant survival (USACOE on-line data 1997). Many mitigative techniques exist for downstream passage and prevention or reduction of entrainment. Standard techniques, like the one currently employed at Bonneville Dam Powerhouse 1 (B1), involve the physical exclusion of outmigrants into a bypass or diversion system by a screening facility.

Various screen types such as fixed, pivoting, and traveling screens are usually employed in bypass systems. Conventional screens such as the fixed inclined screen, submerged traveling screen, inverted or declined screen, fixed angled screen, angled drum screen, angled traveling screen, louvers, and angled bar racks employ "low velocity" design criteria and typically require a large screen area. High velocity screens such as the Eicher screen and the modular inclined screen (MIS) can function at water velocities approaching the screen face up to 10 feet per second (fps). High velocity screens are less expensive than conventional screens because they involve approximately 10% of the screening area than conventional screens (OTA 1995).

The goal of the Task 2A is to prepare an annotated bibliography covering the information cited in the literature review (Task 1). Specifically, the annotated bibliography contains the reviews of 37 documents related to high velocity and high volume dewatering systems. All reviews include an abstract of the document (if abstract was available) and are structured to answer specific questions regarding the results and thoroughness of the studies. The annotated bibliography was compiled in End Note 2 Plus, a database manager that provides a searchable bibliography (Niles & Associates, Inc. 1997). In addition, one electronic copy of each source used in the annotated bibliography was prepared in .PDF format (excluding licensed materials such as the eight Electric Power Research Institute documents) for a total of 29 .PDF files.

Section 2 of this document contains a list of all sources cited in the annotated bibliography. Each document contains a record number that was used to file the document as it was received by R2 Resource Consultants, Inc. (R2). The record number is reflected at the end of each citation in the annotated bibliography list (Section 2).

Section 3 contains a print-out of the annotated bibliography of high velocity and high volume dewatering systems in MS Word format. The annotated bibliography is arranged in numeric order, by the record number. The record number was used as the header in Section 3, as numerous citations contained similar author names and dates. In the future, documents may be added to the annotated bibliography by record number, thus precluding the need to reorganize the entire document in alphabetical order.

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2.0 Bibliographic List

Amaral, S. V., F.C. Winchell, T.C. Cook, and E.P. Taft. 1994. Biological evaluation of a modular inclined screen for protecting fish at water intakes. Report Number TR-104121 Research Project. Prepared by Stone and Webster Engineering Company for the Electric Power Research Institute. Palo Alto, California. 126 pp. Record Number 28.

Anonymous. 1994. A modular inclined fish screen. American Institute of Fishery Research Biologists Newsletter, April 1994 23:2-3. Record Number 1.

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Bomford, J. A., and M.G. Lirette. 1991. Design, operation, and evaluation of an inverted, inclined, outmigrant screen. Pages 228-236 *in* J. Colt and R.J. White editors. Fisheries bioengineering symposium. American Fisheries Society Symposium 10, Bethesda, Maryland. Record Number 2.

Cook, T. C., E.P. Taft, G.E. Hecker, and C.W. Sullivan. 1993. Hydraulics of a new modular fish diversion screen. Pages 318-327 *in* W. D. H. editor. Waterpower '93. Nashville, Tennessee. Record Number 3.

Cramer, D. 1997. Evaluation of a louver guidance system and Eicher screen for fish protection at the T.W. Sullivan plant in Oregon. Presented at the Fish Passage Workshop. Milwaukee, Wisconsin. 14 pp. Record Number 4.

Electric Power Research Institute. 1997. Compact fish screen makes the grade. Hydro Plant News. Spring 1997. 1 pp. Record Number 27.

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Knight, J. W., and D.J. Salisbury. 1997. British Columbia Hydro's commitment to the environmental movement: Puntledge River Hydro Intake Facility. Pages 2231-2250 *in* D.J. Mahoney editor. Waterpower '97. Atlanta, Georgia. Record Number 36.

Matthews, J. G., and G.J. Birch. 1991. Puntledge diversion Dam permanent fish screen overview study. British Columbia Hydro & Power Authority. Burnaby, British Columbia, Canada. 72 pp. Record Number 34.

Matthews, J. G., and J.W. Taylor. 1994. Design and construction of Eicher penstock fish screens. Prepared for the British Columbia Hydro and Power Authority. Vancouver, British Columbia, Canada. 9 pp. Record Number 6.

Office of Technology Assessment. 1995. Fish passage technologies: protection at hydropower facilities. OTA-ENV-641. U.S. Government Printing Office. Washington, D.C. 167 pp. Record Number 7.

Ruggles, C. P., and R. Hutt. 1984. Fish diversionary techniques for hydroelectric turbine intakes. 149 G 339. Prepared for the Canadian Electrical Association Research and Development. Montreal, Quebec, Canada. 64 pp. Record Number 8.

Shiers, P. F., and E.P. Taft. 1996. Evaluation of the modular inclined screen (MIS) at the Green Island hydroelectric project: 1995 test results. Report Number TR-106498 3672-01. Prepared by Stone & Webster Environmental and Alden Research Laboratories Inc. for the Electric Power Research Institute. Palo Alto, California. 116 pp. Record Number 29.

Smith, H. A. 1993. Development of a fish passage solution at the Puntledge hydro intake facility. Pages 197-204 *in* K. Bates editor. Fish passage policy and technology: proceedings of a symposium. Bioengineering Section American Fisheries Society, Portland, Oregon. Record Number 9.

Smith, H. 1997. Operating history of the Puntledge River Eicher screen facility. Presented at the Fish Passage Workshop. Milwaukee, Wisconsin. 6 pp. Record Number 10.

Sullivan, C. W. 1997. Current hydropower research and development. *In* Department of Energy, National Marine Fisheries Service, and Joan Harn editors. Hydropower research and development. 1 pp. Record Number 24.

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Taft, N. 1990. Developments in fish protection systems. Prepared for the Electrical Power Research Institute. Atlanta, Georgia and Palo Alto, California. 51 pp. Record Number 11.

Taft, E. P., S.V. Amaral, F.C. Winchell, and C.W. Sullivan. 1993. Biological evaluation of a modular fish diversion screen. Pages 177-188 *in* K. B. editor. Fish passage policy and technology: proceedings of a symposium. Bioengineering Section American Fisheries Society, Portland, Oregon. Record Number 12.

Taft, E. P., F.C. Winchell, S.V. Amaral, and T.C. Cook. 1994. Fish protection/passage technologies evaluated by EPRI and guidelines for their application. Report Number TR-104120. Prepared by Stone & Webster Engineering Corporation for the Electric Power Research Institute. Palo Alto, California. 203 pp. Record Number 31.

Taft, E. P., F.C. Winchell, A.W. Plizga, E.M. Paolini, and C.W. Sullivan. 1995. Development and evaluation of the modular inclined screen (MIS). Pages 1742-1751 *in* J.J. Cassidy editor. Waterpower '95. San Francisco, California. Record Number 13.

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Wert, M. A., D.W. Casey, and R.E. Nece. 1987. Hydraulic model evaluation of the Eicher passive pressure screen fish bypass system. Prepared for the Electric Power Research Institute. EPRI AP-5492 Project 1745-18, Final Report. Palo Alto, California. 88 pp. Record Number 18.

Winchell, F. C., and C.W. Sullivan. 1991. Evaluation of an Eicher fish diversion screen at Elwha Dam. Pages 93-102 *in* D. D. Darling editor. Waterpower'91. Denver, Colorado. Record Number 19.

Winchell, F. C., and E.P. Taft. 1992. Evaluation of the Eicher Screen at Elwha Dam: 1990 and 1991 test results. Prepared for the Electrical Power Research Institute. EPRI TR-101704 Project 2694-01, Final Report. Palo Alto, California. 239 pp. Record Number 25.

Winchell, F., N. Taft, T. Cook, and C. Sullivan. 1993. EPRI's evaluation of the Elwha Dam Eicher screen and subsequent design changes and hydraulic tests. Pages 186-196 *in* K. B. editor. Fish passage policy and technology: proceedings of a symposium. Bioengineering Section American Fisheries Society, Portland, Oregon. Record Number 20.

Winchell, F., S. Amaral, N. Taft, and C. Sullivan. 1993. Biological evaluation of a modular fish screen. Pages 328-327 *in* W. D. H. editor. Waterpower '93. Nashville, Tennessee. Record Number 21.

Winchell, F., N. Taft, T. Cook, and C. Sullivan. 1993. Research update on the Eicher screen at Elwha Dam. Pages 344-353 *in* W. D. H. editor. Waterpower '93. Nashville, Tennessee. Record Number 22.

Winchell, F. C., S.V. Amaral, and E.P. Taft. 1994. Research update on fish protection technologies for water intakes. Report Number TR-104122. Prepared by Stone & Webster Engineering Corporation for Electric Power Research Institute. Palo Alto, California. 208 pp. Record Number 30.

Zapel, E. 1997. Howard A. Hanson Dam. Presented at the Fish Passage Workshop. Milwaukee, Wisconsin. 24 pp. Record Number 23.

3.0 Annotated Bibliography

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Journal Article
Record Number: 1
Author: Anonymous
Year: 1994
Title: A modular inclined fish screen.
Journal: American Institute of Fishery Research Biologists
Volume: 23
Pages: 2-3
Abstract: Electric Power Research Institute has been developing a Modular Inclined Screen-a high-velocity fish screen that shows promise for protecting a wide range of fish species. The screen is similar to the Eicher penstock screen, but with a "modular" design, improved hydraulic characteristics, and application to a broad range of water intakes. Unlike the penstock screen, this screen can be placed in canals, forebays, or pumping plant intakes.

The MIS consists of a fully submerged, rectangular culvert, with a trashrack over the entrance; dewatering stoplogs; an inclined wedgewire screen set at a shallow angle of 15 degrees to the flow; and a bypass for diverting fish into a transport pipe. (see plan and section view at right.) The screen is mounted on a pivot shaft so it can be cleaned via rotation and backflushing. Depending on fish species and life stages to be protected, the module can operate at water velocities from 2 to 10 feet per second.

Due to a standardized design size (screens about 10 feet wide by 30 feet long), additional modules can be placed side by side to achieve desired approach velocities. This design may have several advantages over traditional screening systems:

It can operate over a range of fluctuating water levels and flow conditions.
Fish are exposed to the screen for only a short time.
Each module can be dewatered easily.
Because it is compact, cost savings would be significant.

Biological studies are being conducted in a 1:3.33-scaled prototype at Alden Research Laboratory in Holden, Massachusetts. Passage survival above 95 percent was achieved over a range of velocities (2-10 fps) with juvenile (45-170mm) Chinook, coho, and Atlantic salmon. Other species tested, with similar results, include bluegill, walleye, rainbow trout fry, catfish, and alosid juveniles. In fall 1994, a single 1:1.7-scaled unit will be tested in the Hudson River in New York. Additional field studies with delta species will be necessary before the design is acceptable to state and federal regulatory agencies.

<u>DETAILED SUMMARY</u>:

A brief summary of what a modular inclined screen is, including findings from Alden Research Laboratory in Holden, Massachusetts.

Lab or Field

review of ongoing tests

Biological or Hydraulic

Biological

species and size of test fish

chinook, coho, Atlantic salmon (45-170 mm)

hatchery or wild

did not report

range of velocities tested

2-10 fps

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

survival above 95%

Mechanical

screen mesh design and porosity

did not report

screen length/exposure time

one module = 30 ft long X 10 ft wide

screen angle

15°

seal durability

did not report

screen design loading

did not report

Bypass

volume of bypass flow relative to screen

did not report

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- see Winchell et al. (1993) for complete study results

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Book
Record Number: 2
Author: Bomford, J. A., and M.G. Lirette
Year: 1991
Title: Design, operation, and evaluation of an inverted, inclined, outmigrant screen.
Series Title: Fisheries bioengineering symposium.
Series Editor: J. Colt and R.J. White
Publisher: American Fisheries Society Symposium 10
City: Bethesda, Maryland
Number of Pages: 228-236
Abstract: A unique screening device for juvenile fish has been built on, and is operating in, a hydroelectric canal on Vancouver Island, British Columbia. The canal diverts up to 42.5 ml/s, and the screen is designed to remove outmigrant smolts of steelhead *Oncorhynchus mykiss* and coho salmon *0. kisutch* from the canal inflow and return them to the Salmon River. The 25-m-long by 6.7-m-wide screen is supported on a removable steel truss suspended in a rectangular section of the canal flowing at a depth of 2.9 m. It incorporates 170 ml of slotted woven-wire-mesh screen, and when in service, it inclines downward in the downstream direction, forcing fish into a collector resting on the canal floor at its lower end. The collector diverts the fish laterally out of the canal and into the bypass works. The bypass works consist of a flow-regulating channel, trap, and return pipe to the river. The entire facility is designed to operate passively, in a structurally fail-safe manner, and without power or full-time operator attendance. During two operating seasons (April 15 to June 30, 1987-1989), the facility was 80% efficient, based on mark-recapture studies of small samples of yearling coho salmon smolts. Although the screen provides less than 100% protection, because of compromises required by budgetary constraints, it is a practical, cost-effective alternative to more conventional designs. With appropriate design modifications, this type of screen could function with higher efficiencies at little additional cost, and in streams with fish of all life stages.

DETAILED SUMMARY:

Lab or Field
Field
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - coho (high velocity)
    - steelhead (low velocity)
  - **hatchery or wild**
    - hatchery
  - **range of velocities tested**
    - high = 0.2 m/s (0.66 fps) - 0.4 m/s (1.31 fps)

water temperature and clarity
did not report
results of test by species, velocity, screen porosity etc...
coho (70mm) 0.2 m/s (0.66 fps) 89, 86, 68% efficiency
coho (70mm) 0.4 m/s (1.31 fps) 89, 79, 86, 71% efficiency

Mechanical
screen mesh design and porosity
2 mm triple shute woven-wire mesh w/ 12 mm X 100mm openings

70% porosity
screen length/exposure time
25 m long by 6.7 m wide
screen angle
6.5°
seal durability
10 mm neoprene rubber flaps
screen design loading
did not report

Bypass
volume of bypass flow relative to screen
1.5 (4.9 ft) m long X 0.25 m (0.82 ft) deep
maximum velocity of bypass flow
0.4 m/s (1.31 fps) - 0.9 m/s (2.95 fps)
bypass to screen approach velocity ratio
did not report

Debris loading
cleaning frequency
once per day (on avg)
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
This is a canal intake structure built in 1957, consisting of a timber crib dam and concrete head works. A radial gate controls the discharge into the trapezoidal-shaped canal.

Other:

- Tests were conducted in 1987 on 3 groups of steelhead and 1 group of coho smolts, but the fish collection facility did not work and data was precluded (20%, 44%, 41%, 7% survival).

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 3
Author: Cook, T.C., E.P. Taft, G.E. Hecker, and C.W. Sullivan
Year: 1993
Title: Hydraulics of a new modular fish diversion screen.
Conference Name: Waterpower '93
Editor: W.D. Hall
Conference Location: Nashville, Tennessee
Volume: 1
Pages: 318-327
Abstract: To prevent fish from passing through turbines, EPRI has developed a new laboratory modular inclined Screen (MIS) concept. Various laboratory flow facilities have used to test MIS for fish sceening efficiency and flow characteristics. Data for these tests show high efficiencies and favorable hydraulics for a wide range of approach velocities.

<u>**DETAILED SUMMARY**</u>:

Lab or Field
Laboratory hydraulic tests on a 1:6.66 and a 1:3.33 versions of a MIS
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - not applicable
  - **hatchery or wild**
    - not applicable
  - **range of velocities tested**
    - 0.6 - 3.0 m/s (1.97 - 9.84 fps)
  - **water temperature and clarity**
    - not applicable
  - **results of test by species, velocity, screen porosity etc...**
    - not applicable
- **Mechanical**
  - **screen mesh design and porosity**
    - Hendrick profile bar 1.9 mm spacing; 30 and 50% porosity
  - **screen length/exposure time**
    - did not report
  - **screen angle**
    - 10°, 15°, and 20°
  - **seal durability**
    - did not report
  - **screen design loading**
    - did not report

Bypass

volume of bypass flow relative to screen

flume flow exceeded 2.83 m^3/s (100 cfs)

maximum velocity of bypass flow

in steel flume that was 2.1 m deep (7 ft) by 1.8 m wide (6 ft)

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- Normalized velocities (non-dimensionalized by dividing by the average approach flow) were nearly constant with velocities ranging from 0.61 - 3.05 m/s (2 - 10 fps), even when approach velocities were skewed as much as 45 .
- Overall, the head loss for a typical design velocity of 1.8 m/s (6 fps) would be 0.3m (0.95 ft).
- The head loss through the bypass was smaller than through the screen.

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 4
Author: Cramer, D.
Year: 1997
Title: Evaluation of a louver guidance system and Eicher screen for fish protection at the T.W. Sullivan plant in Oregon.
Institution: Presented at the Fish Passage Workshop
City: Milwaukee, Wisconsin.
Date: 6-8 May, 1997
Pages: 14
Abstract: The T.W. Sullivan Plant is a run of the river diversion project on the Willamette River in Oregon. The Project has 13 turbines and at full load draws about 5,200 cubic feet per second (cfs) to produce 16.6 megawatts. Since 1972 Portland General Electric (PGE) has been modifying and evaluating a system to safely pass juvenile migrant salmonids. Forebay trash racks were slightly modified to act as louvers and a training wall added to provide a more laminar flow. Fish are guided through the forebay past the first 12 units to unit 13. In 1980 the unit 13 penstock was retrofitted with an Eicher pressure screen to divert fish into a bypass pipe leading to a fish evaluation area. Flow through unit 13 is approximately 400 cfs while flow through the bypass is maintained at 50 cfs. With the current facility configuration, fish entering the forebay exhibit average bypass efficiencies of 92%, 82% and 85% for spring chinook *(Oncorhynchus tshawytscha.),* fall chinook and steelhead *(Oncorhychus mykiss)* respectively. Over 500,000 fish were examined for injury and descaling from 1991 through 1995. The average occurrence of injury and descaling, for all species all years, was 0.44% and 1.81% respectively.

<u>DETAILED SUMMARY</u>:

Lab or Field
field
Biological or Hydraulic
Biological
species and size of test fish
fall and spring chinook
steelhead
hatchery or wild
hatchery and wild fish
range of velocities tested
6 fps = penstock velocity
water temperature and clarity
10 day cycles through the system do not allow test of specific conditions

results of test by species, velocity, screen porosity etc...

	avg guidance efficiency (guided past first 12 units)	
spring chinook (140 - 295 mm)	90%	
fall chinook (85 - 150 mm)	82%	
steelhead (159 - 290 mm)	82%	
	injury	**descaled**
all species combined (1991-1995)	0.44%	1.81%
	delayed mortality (48 hr)	
spring chinook (1993-1996)	1.32%	
fall chinook (1993-1996)	2.05%	
steelhead (1993-1996)	0.32%	

Mechanical

screen mesh design and porosity

wedge-wire screen with 2mm bars and 2 mm openings between bars

screen length/exposure time

calculated = 21/cos(19)= 22.2 ft

screen angle

19°

seal durability

did not report

screen design loading

250 lbs/ft^2

Bypass/Penstock

volume of bypass flow relative to screen

penstock capacity approximately 450 cfs (10 ft wide X 21 ft long)
400 cfs to turbine 50 cfs to fish bypass system
fish are then separated to 14 cfs by a bar screen to the test channel
fish pass over an inclined screen to a 6 inch pipe to holding box

maximum velocity of bypass flow

6 fps avg penstock velocity

bypass to screen approach velocity ratio

6:1.6 fps

Debris loading

cleaning frequency

automated process when head differential equals 18-20 inches

duration of cycle

total cleaning time is 19 minutes

timing of cycle (season)

debris loading problems in the fall
twice per day avg cycling
one cycle/hr if heavy debris loading event

factors affecting load (reservoir size, watershed characteristics, elevation)

time of year (increased during fall freshets)

Other:

- Eicher Screen was installed in 1980, results of this paper are for the current configuration in existence since 1992.
- Fish enter the forebay and are entrained into penstock 13 through cylindrical bar trash racks with 5 inch spacing.
- appears to be a positive relationship between guidance efficiencies and head (pool elevation)
- lowest head levels were associated with high levels of debris

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 5
Author: ENSR Consulting and Engineering
Year: 1993
Title: Final Report Puntledge River diversion dam permanent fish screen project hydraulic model studies.
Institution: Prepared for British Columbia Hydro and Power Authority, Vancouver, British Columbia, Canada.
Date: December 1993
Type of Work: Final Report
Report Number: 0813-001-510
Pages: 45
Abstract: This report presents the results of a 1:10.96-scale physical hydraulic model study that was conducted to assist British Columbia Hydro and Power Authority (B.C. Hydro) in the design of a permanent fish diversion screen for the intakes to the Puntledge River Hydroelectric Project.

The objectives of the hydraulic model study were to

1. Provide necessary information for the final design of the proposed penstock screens for the Puntledge Project penstocks

2. Optimize the overall layout and design details of the installation with respect to its hydraulic performance

3. Confirm that the hydraulic performance of the final design satisfies the criteria established for the project

The project presently includes a diversion dam, a side channel with an uncontrolled overflow spillway along the right bank, an intake structure at the end of the spillway, and a single wood stave-steel penstock leading to a powerhouse located approximately 4 miles downstream.

Hydroelectric development on the lower Puntledge River has resulted in several direct and indirect impacts on the salmonid fishery.

B.C. Hydro has addressed these and other fisheries issues on a continuous basis. Recently, B.C. Hydro has been focusing on the problem of juvenile mortality at the hydroelectric turbines. Their approach has been to divert the fish from the hydro intakes and return the fish to the river.

B.C. Hydro studied five types of screening systems that were considered feasible for the Puntledge site: louvers, horizontal or inclined fixed screens, vertical fixed screens, rotating

drum screens, and penstock screens. The penstock screen alternative was selected. The screen design was similar to the installation at the Elwha project in Washington State.

The purpose of the penstock screen is to guide fish in the penstock to a pipe connection at the boundary of the penstock. The pipe returns the fish and a small percentage (about 25 cfs) of the penstock water to the river. An improperly designed penstock screen can injure and kill fish, create unacceptably high head losses, and result in high maintenance costs. Therefore, optimum screen design must take into account fish behavior and swimming characteristics, minimize hydraulic head loss, and be easy to clean and maintain.

The proposed project includes constructing two new 10.5-foot-diameter penstocks in intakes No. 3 and No. 4. Each new penstock will be connected to the intake structure using an 8.5-foot by 10.54oot expansion piece. A permanent penstock screen will be constructed in each of the new 10.5-foot-diameter penstocks. The new penstocks will be connected to a new section of 12-foot-diameter penstock using a wye-fitting at some distance downstream of the screens. The new 12-foot-diameter penstock will be connected to the existing penstock.

Each of the penstock screen systems will contain a bypass pipe that will convey fish out of the penstocks to the river below the penstock intakes.

B.C. Hydro and the Department of Fisheries and Oceans (DFO), in consultation with U.S. National Marine Fisheries Service (NMFS), ENSR, Eicher and Associates, Harza Northwest, and others, developed a set of screen performance criteria that was considered appropriate for the Puntledge penstock screen.

The model was operated as a Froude-scaled model to develop the approach flow conditions to the model screen. Screen velocities and head losses were measured while operating in the calibrated Reynolds condition.

The initial test was performed with a uniform porosity screen. The screen performance criteria was largely met with this screen. However, in an attempt to improve upon this, five other screen configurations were tested. The changes in screen porosity did not significantly adjust the distribution of flow along the screen. Head losses, however, were higher with the modified screens. Therefore, B.C. Hydro, in consultation with ENSR, decided to use the originally proposed screen for final design.

The head loss of the final screen system was 1.29 feet with an average penstock velocity of 6 fps and a bypass velocity of 8 fps. Approximately 60 percent of the head loss was attributable to the screen support system.

The design of the bypass conduit was modified to reduce the separation zone that occurred downstream of the intersection of the entrance transition side wall and the start of the horizontal bend of the bypass conduit. Addition of a 12-foot-long tangent section upstream of the curved conduit resulted in satisfactory performance.

The model tests indicate that a penstock screen installation having the features included in this study can meet the performance criteria of the Puntledge project without variable screen porosity or added baffles.

DETAILED SUMMARY:

Lab or Field
Laboratory hydraulic test using a 1:10.96 model assess the hydraulic performance of the screen in relation to the screen performance criteria.
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - not applicable
  - **hatchery or wild**
    - not applicable
  - **range of velocities tested**
    - criteria = 3-6 fps approach velocity
    - 3:1 sweeping:approach velocity ratio
    - uniform (±20%) approach velocities
  - **water temperature and clarity**
    - not applicable
  - **results of test by species, velocity, screen porosity etc...**
    - not applicable
- **Mechanical**
  - **screen mesh design and porosity**
    - six screen porosity's were tested by adding baffles to the screen
    - original design was Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing
  - **screen length/exposure time**
    - 1:10.96 scale model
  - **screen angle**
    - 16.5°
  - **seal durability**
    - did not report
  - **screen design loading**
    - did not report
- **Bypass/Penstock**
  - **volume of bypass flow relative to screen**
    - criteria = 25 cfs
  - **maximum velocity of bypass flow**
    - criteria = 8 fps
  - **bypass to screen approach velocity ratio**
    - criteria = 8:6 fps
- **Debris loading**
  - **cleaning frequency**

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- none of the six screen configurations tested affected the distribution of flow along the screen
- the original screen design caused a head loss of 1.29 ft with an average penstock velocity of 6 fps and bypass velocity of 8 fps
- all hydraulic performance criteria were met under the 1:10.96 model with original screen design

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 6
Author: Matthews, J.G., and J.W. Taylor.
Year: 1994
Title: Design and construction of Eicher penstock fish screens.
Institution: Prepared for the British Columbia Hydro and Power Authority
City: Vancouver, British Columbia, Canada.
Pages: 9
Abstract: A penstock screen design, patented by George Eicher, was developed to accommodate site conditions at Puntledge Dam. The screen removes juvenile anadromous fish from the power flow and returns them to the river downstream of the dam. Turbine mortality, which was greater than 60% of the annual migration, has been eliminated. Mortality through the screen and bypass facility is less than 1 %. A 1:10.96 scale hydraulic model was constructed to assist in design and evaluate hydraulic performance of the screen. Construction of screens, fish bypass pipes and an evaluation facility was completed in May 1993.

DETAILED SUMMARY:

Lab or Field
An overview of the Puntledge River Eicher Screen project.
Biological or Hydraulic
no tests were conducted
Biological
species and size of test fish
designed for 37 mm chinook
hatchery or wild
hatchery and wild
range of velocities tested
facility design criteria = 1.83 m/s (6.0 fps)
sweeping velocity:normal velocity ratio $\geq$ 3:1
± 10% maximum variation in velocity immediately upstream of screen
water temperature and clarity
not applicable
results of test by species, velocity, screen porosity etc...
fish mortality associated with the hydroelectric facility has dropped from 60% before the screen to less than 1%
Mechanical
screen mesh design and porosity
Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing

screen length/exposure time
12.8 m long (42 ft)
screen angle
16.5°
seal durability
did not address
screen design loading
did not address

Bypass/Penstock
volume of bypass flow relative to screen
3.2 m (10.5 ft) diameter penstock
0.61 m (2 ft) diameter bypass pipe discharging 0.71 m^3/s (25.1 cfs)
maximum velocity of bypass flow
design criteria = 2.44 m/s (8 fps)
bypass to screen approach velocity ratio
design criteria = 2.44 m/s (8 fps):1.83 m/s (6 fps)

Debris loading
cleaning frequency
did not report
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
pressure sensors cycled the screen when head loss reached a preset level

if facility is operated at partial load for extended periods, debris will build up in the forebay which hits the screen in on "slug" when the plant

Other:

- total cost of the project was $4,750,000
- black fly (Sumulidae) larvae accumulation causes increase debris accumulation and needs to be pressure washed each fall

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 7
Author: Office of Technology Assessment
Year: 1995
Title: Fish passage technologies: protection at hydropower facilities.
Institution: U.S. Government Printing Office
City: Washington, D.C.
Date: September 1995
Report Number: OTA-ENV-641
Pages: 167
Abstract: The incomplete state of knowledge regarding fish population dynamics, the impacts of hydropower development on fish, the need for mitigation in various contexts, and the protection/ passage effectiveness of available mitigation technologies exacerbates the sometimes adversarial relationships among stakeholders. This situation is unlikely to be alleviated unless a solid, science-based process for mutual understanding and rational decision making can be developed.

A combination of academic, government, and industry expertise is needed in a concerted effort to focus science and technology resources on the question of the effects of hydropower development on fish population sustainability; and on the assessment of available and developing fish passage and protection technologies at hydropower facilities.

Technologies

Technologies for upstream passage are more advanced than for downstream passage, but both need more work and evaluation. Upstream passage failure tends to result from less-than-optimal design criteria based on physical, hydrologic, and behavioral information, or lack of adequate attention to operation and maintenance of facilities. Downstream fish passage technology is complicated by the limited swimming ability of many down-migrating juvenile species and by unfavorable hydrologic conditions. There is no single solution for designing up- and downstream passageways; however, both types must be designed and applied in such a manner that in theory, model, and reality they should suit the range of conditions at the sites structurally, hydraulically, and biologically. Effective fish passage design for a specific site requires good communication between engineers and biologists and thorough understanding of site characteristics.

Downstream passageways for fish and protective measures to reduce turbine mortality are probably the areas most in need of research. Many evaluations of conventional and alternative technologies have not been conducted with scientific rigor. This results in unsubstantiated claims and arguments. Moreover, some experimental results contradict others. Ambiguous or equivocal results of many fish passage studies have caused concern as to whether certain technologies are effective or generally useful. The variability of

results may reflect site variability; uncontrolled environmental conditions in field studies; or incomplete knowledge of fish behavior. Thus, some performance claims may be based on incomplete assessments. Advocates on both sides of the fish/power issue can select from a diverse body of scientifically unproved information to substantiate their points of view. Care must be taken in interpreting much published information on fish protection, arguments drawn from it, and conclusions reached. When good scientific research and demonstration is carried out, results can be dramatic.

Hydropower Licensing

Controversy abounds in the FERC hydropower licensing process. In part, this may be a result of the lack of clearly identified goals to be achieved through mitigation. Although objectives exist in the legislative language of the FPA, as amended, these lend themselves more to a philosophy than to hard goals that describe numbers, time frames, and methods for achieving and measuring the stated goal. Clearly defined goals for protection and restoration of fish resources might refer to numbers or percentages of fish expected to successfully pass a barrier and/or projected population sizes. Since resource management goals are rarely articulated, mitigation and enhancement measures are judged on a case-by-case basis, with no means for assessment or comparison.
The lack of clear goals is, in part, reflected in the disjunction between section 18 prescriptions and section 100) recommendations of the FPA. Section 18 fish passage prescriptions are mandatory; however, section 100) recommendations may be altered based on consistency with other applicable law or the goals for the river (e.g., whitewater rafting/recreation, power production needs). Yet, the recommendations made under section 100) may be critical to maintaining habitat for fish populations or promoting timely migrations for certain species. FERC, as the final authority for balancing developmental and nondevelopmental values, is not specifically charged with sustaining fish populations. Without clear identification of the goal for mitigation, monitoring and evaluation become less meaningful and fail to become critical to the process.

Monitoring and evaluation conditions for hydropower licenses are infrequently enforced, resulting in little information on how effective available mitigation technologies are in improving fish passage and survival at hydropower plants. Operation and maintenance failures have been implicated in poor efficiency of fishways. Forty percent of nonfederal hydropower projects with upstream fish passage mitigation have no performance monitoring requirements. Those that do generally only quantify passage rates, without regard to bow many fish arrive at and fail to pass hydropower facilities. Moreover, most monitoring has dealt with anadromous salmonids or clupeids; much less is known about the effectiveness of mitigation measures for "less-valued" or riverine fish. Research is needed to determine whether river blockage is even negatively affecting riverine species.

Relicensing decisions often are not based on river-wide planning and cumulative analysis. FERC is required to review existing river management plans to assure that the project will not interfere with the stated goals (pursuant to section 10(a) of the FPA). Yet, comprehensive river basin planning is fragmented. Synchronizing license terms on river basins could improve the relicensing process and promote cumulative impact analyses. Terms could be adjusted to meet the ecological needs of the basin and to provide timeliness and predictability for licensees. Under such a plan, multiple sites could be relicensed simultaneously, although operators may be unlikely to respond positively to undergoing the relicensing process "early." On the other hand, consolidation could yield benefits, allowing licensees to develop integrated management plans to maximize the energy and capacity values of their projects; making it easier for all involved parties to view the projects and their impacts in their totality; and facilitating understanding of cause and effect relationships.

There is a need for further research on cumulative fish passage impacts of multiple projects, and for consideration of fish needs at the watershed level. In several northeastern states, cooperative agreements between resource agencies and hydropower companies have generated successful approaches to basin-wide planning for fish protection. Carefully planned sequential construction and operation of fish passages could provide significant opportunities for restoring historic fish runs. In the western states, watersheds on national forests provide about one-half of the remaining spawning and rearing habitat for anadromous fish in the United States. Ecosystem or watershed management in these areas could have immediate and long-term impacts on fish populations.

The following chapters provide detailed information about current understanding about the need for fish passage and protection associated with hydropower facilities (chapter 2); the status of fish passage technologies, both conventional and emerging (chapters 3 and 4); and the federal role in fish passage at hydropower facilities (chapter 5). Appendices provide historical information on fish passage research in the Columbia River Basin (appendix A); experimental guidance devices and resource agency policy statements (appendix B); and additional suggested readings related to fish passage technology issues (appendix C).

DETAILED SUMMARY:
Review of the technology pertaining to fish passage, including a chapter on downstream fish passage technologies that covers the Eicher Screen and modular inclined screen (MIS).

Lab or Field

Biological or Hydraulic

Biological

species and size of test fish

not applicable

hatchery or wild

not applicable

range of velocities tested

not applicable

water temperature and clarity

not applicable

results of test by species, velocity, screen porosity etc...

not applicable

Mechanical

screen mesh design and porosity

not applicable

screen length/exposure time

not applicable

screen angle

not applicable

seal durability

not applicable

screen design loading

not applicable

Bypass/Penstock

volume of bypass flow relative to screen

not applicable

maximum velocity of bypass flow

not applicable

bypass to screen approach velocity ratio

not applicable

Debris loading

cleaning frequency

not applicable

duration of cycle

not applicable

timing of cycle (season)

not applicable

factors affecting load (reservoir size, watershed characteristics, elevation)

not applicable

Other:

- the Elwha Eicher Screen had nearly 99% diversion efficiency for some species and life stages
- the Puntledge River Eicher screen indicate 99.2% guidance success of coho yearlings
- in a study for Electric Power Research Institute, nearly 100% of the test fish were diverted alive (adjusted mortality <1%) while testing a modular inclined screen at Alden Research Laboratories
- the modular inclined screen will be tested in the field at Niagara Mohawk's Green Island facility on the Hudson River in 1995
- both the Eicher and Modular inclined screens violate most federal and state screening criteria, however they operate under the assumption that both fish swimming ability and stamina are inconsequential to the functionality of the screen

- in Appendix B, the National Marine Fisheries Service position statement on guidance devices is given

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 8
Author: Ruggles, C.P., and R. Hutt
Year: 1984
Title: Fish diversionary techniques for hydroelectric turbine intakes.
Institution: Prepared for the Canadian Electrical Association Research and Development.
City: Montreal, Quebec, Canada.
Date: January 1984
Report Number: 149 G 339
Pages: 64
Abstract: A number of fish screens are described and evaluated in terms of their potential for removing fish from hydroelectric turbine intakes. Six fish diversionary techniques are identified as practical or promising. Both physical barrier screens and behavioral barriers are discussed. Fish screening at hydroelectric intakes in Canada is reviewed and areas for future Canadian research identified. It is concluded that screening turbine intakes is not justified, except on rivers supporting valuable runs of migratory fishes.

DETAILED SUMMARY:
Summary of 23 fish diversionary techniques. All but one, Eicher Pressure Screen, utilized low velocity screening criteria.

Lab or Field

Biological or Hydraulic

Biological

species and size of test fish

did not report

hatchery or wild

did not report

range of velocities tested

1.7 m/s (5.6 fps) - 2.1 m/s (6.9 fps)

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

no mortalities attributable to the Eicher Screen have been found, although some descaling has occurred.

Mechanical

screen mesh design and porosity

Johnson wedge-wire screen with 2 mm bars and 2 mm openings

screen length/exposure time

75 ft^2

screen angle
19°
seal durability
did not report
screen design loading
did not report

Bypass/Penstock
volume of bypass flow relative to screen
did not report
maximum velocity of bypass flow
bypass flows are important to sweep fish into the bypass
bypass velocity = 6.6 fps are required
bypass to screen approach velocity ratio
did not report

Debris loading
cleaning frequency
did not report
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- An outdated research report that was published just as the high velocity dewatering screens (Eicher Screens) were introduced.
- wild coho, chinook, and steelhead were tested in the Willamette River, Oregon while juvenile chinook and rainbow trout were tested at the University of Washington, Seattle

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 9
Author: Smith, H. A.
Year: 1993
Title: Development of a fish passage solution at the Puntledge hydro intake facility.
Conference Name: Fish passage policy and technology: proceedings of a symposium.
Editor: K. Bates
Publisher: Bioengineering Section American Fisheries Society
Conference Location: Portland, Oregon.
Pages: 197-204
Abstract: The Puntledge River was developed for hydroelectric purposes in 1913 and was later redeveloped with increased penstock flows in 1957. Difficulties in implementing fish protection measures at that time led to a decision to close the river above the dam to fish passage. In 1988 a decision was made to regain natural production from habitat above the dams. Upstream passage was in place and a means to protect downstream migrant chinook salmon (Oncorhynchus, tshawytscha), coho salmon (0. kisutch) and steelhead trout (0. mykiss) as required. Initial work concentrated on the use of behavioral deices including strobe lights, a fish hammer and a chain curtain. Bypass diversion rate was in the order of 8.6%. In 1990 a graduated electric field guidance system was tested with 11.1% of the coho smolts being diverted. In 1991 and 1992 a temporary fish diversion net was used to divert 99% of test fish in both low flow years. The temporary net was designed to operate at normal controlled stream flows of 1100 to 1200 cfs and would not function during uncontrolled freshet flows. The Eicher screen was chosen as the permanent solution following a review of existing designs and site limitations. A design was prepared and tested and construction was completed in May 1993. Fish diversion at the site in the first year of operation was 99.8% for the 8,900 juvenile coho migrants tested.

DETAILED SUMMARY:

Lab or Field
Biological test of the Puntledge River Eicher screen during 1993.
Biological or Hydraulic
Biological
species and size of test fish
coho
chinook
hatchery or wild
hatchery and wild coho and chinook
range of velocities tested
did not address but addressed in other papers
facility design criteria = 1.83 m/s (6.0 fps)
sweeping velocity:normal velocity ratio = 3:1

water temperature and clarity
did not report
results of test by species, velocity, screen porosity etc...

mortality of fish passing through Eicher Screen

species	n	year	% 96 hr mort.
coho	7670	1993	0.13
chinook	379	1993	1.1

fish classified as descaled (16% on one side or 40% on 2 of 5 zones)

species	n	year	% descaled
coho	314	1993	2.2

Mechanical
screen mesh design and porosity
did not address, but addressed in other papers
Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing
screen length/exposure time
did not address, but addressed in other papers
12.8 m long (42 ft)
screen angle
16.5°
seal durability
did not report
screen design loading
did not report
Bypass/Penstock
volume of bypass flow relative to screen
3.2 m (10.5 ft) diameter penstock
0.61 m (2 ft) diameter bypass pipe discharging 0.71 m^3/s (25.1 cfs)
maximum velocity of bypass flow
design criteria = 2.44 m/s (8 fps)
bypass to screen approach velocity ratio
design criteria = 2.44 m/s (8 fps):1.83 m/s (6 fps)
Debris loading
cleaning frequency
4 hour cycle in 1993
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
most of debris is captured via a log boom and 2 inch aperture trash rack

pressure sensors cycled the screen when head loss reached a preset level

Other:

- 1993 results are partial as of this manuscript
- Comox Lake acts as a buffer to variations in watershed runoff and aids in debris management
- installation of the Eicher Screen came after the failure of behavioral devices, strobe lights, fish hammer, and chain curtain to divert juvenile salmonids past turbines that were estimated to cause 60% mortality
- preliminary results indicate that a large portion of the mortalities and descaling occur in the evaluation chamber

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 10
Author: Smith, H.
Year: 1997
Title: Operating history of the Puntledge River Eicher screen facility.
Institution: Presented at the Fish Passage Workshop
City: Milwaukee, Wisconsin.
Date: 6-8 May, 1997
Pages: 6
Abstract: High turbine mortality levels were identified during the early history of the Puntledge River powerplant. In 1957 a decision was made to curtail access to headwater habitats and an attempt was made to use fish culture methods to maintain anadromous stocks. Declining stocks and the need to regain use of headwater habitats, necessitated the consideration of alternatives for fish passage protection. Several behavioral methodologies were tested including strobe lights, Fish Scram sound generator and an electric field. Behavioral methodologies resulted in limited success with bypass efficiencies ranging from 8% to 11%. A temporary net barrier resulted in a bypass effectiveness in excess of 99% for the low discharges tested. Finally, an Eicher penstock screen was installed as the permanent solution. Test results during a two year experiment showed a bypass efficiency for coho and chinook salmon smolts in excess of 99% for all expected discharge conditions. Analysis of bypass efficiencies for steelhead, sockeye and chum salmon fry, on an opportunistic basis, provided bypass rates of 100%, 96% and 96% respectively. Several operational considerations are discussed in the paper.

<u>DETAILED SUMMARY</u>:

Lab or Field
Biological test of the Puntledge River Eicher screen during 1993 and 1994.

Biological or Hydraulic

Biological

species and size of test fish
- coho
- chinook
- sockeye
- chum
- steelhead

hatchery or wild
- hatchery and wild coho and chinook
- wild steelhead
- wild sockeye
- hatchery chum

range of velocities tested

facility design criteria = 1.83 m/s (6.0 fps)

sweeping velocity:normal velocity ratio = 3:1

water temperature and clarity

did not address

results of test by species, velocity, screen porosity etc...

mortality of fish passing through Eicher Screen

species	length (mm)	n	year	% dir. mort.	% 96 hr mort.	% total mort.
coho	84-135	9758	1993	0.05	0.13	0.18
coho	84-135	5184	1994	0.06	0.05	0.11
chinook	69-115	1442	1993	0.14	0.58	0.72
chinook	69-115	698	1994	0.00	0.19	0.19
sockeye	96-155	31	1993	0.00	4.17	4.17
sockeye	96-155	131	1994	1.53	2.17	3.70
trout	264-310	14	1993	0.00	0.00	0.00
chum	41-54	424	1994	0.94	2.60	3.54

fish classified as descaled (16% on one side or 40% on 2 of 5 zones)

species	n	year	% descaled	cntrl. scale loss (n)
coho	340	1993	3.8	1.6 (63)
coho	286	1994	4.4	
chinook	264	1993	5.3	4.0 (24)
chinook	181	1994	3.3	
sockeye	10	1993	20.0	
sockeye	64	1994	12.5	
steelhead	2	1993	0.0	
steelhead	6	1994	0.0	

Mechanical

screen mesh design and porosity

did not address, but addressed in other papers

Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing

screen length/exposure time

did not address, but addressed in other papers

12.8 m long (42 ft)

screen angle

16.5°

seal durability

rubber seals have remained intact and functional over 5 years

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

3.2 m (10.5 ft) diameter penstock

0.61 m (2 ft) diameter bypass pipe discharging 0.71 m^3/s (25.1 cfs)

maximum velocity of bypass flow

design criteria = 2.44 m/s (8 fps)

bypass to screen approach velocity ratio

design criteria = 2.44 m/s (8 fps):1.83 m/s (6 fps)

Debris loading

cleaning frequency

4 hour cycle in 1993

a pressure sensor was installed in 1994 to cycle the screen when pressure

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

small debris (< 2 in) may enter the penstock

most of debris is captured via a log boom and 2 inch aperture trash rack

in 1996, cleaning systems were unable to manage debris on 2 occasions, causing the penstock intake gate closure

Other:

- Comox Lake acts as a buffer to variations in watershed runoff and aids in debris management
- pressure sensor units of laboratory quality may be replaced with field quality because they were failing at critical periods due to debris and dirt
- black fly (Simulidae) colonization of the screen has caused screen porosity restriction resulting in maintenance work consisting of pressure washing

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 11
Author: Taft, N.
Year: 1990
Title: Developments in fish protection systems.
Institution: Prepared for the Electrical Power Research Institute by Stone & Webster Environmental Services
City: Atlanta, Georgia and Palo Alto, California
Date: June 1990
Type of Work: EPRI Relicensing Workshops
Pages: 51
Abstract: No abstract. Document consists of 51 figures.

DETAILED SUMMARY:

Lab or Field
A compilation of tables and figures that summarize the developments in fish protection systems, including Eicher Screens located in the Willamette and Elwha rivers, up to 1990. Lists the design specifications and initial test results of the Elwha River Eicher Screen.

Biological or Hydraulic
Results are preliminary and pertain only to the Elwha River Eicher Screen.

Biological

- **species and size of test fish**
  - coho (110 - 120 mm)
  - chinook (70 - 90 mm)
  - steelhead (190 - 210 mm)
- **hatchery or wild**
  - did not report
- **range of velocities tested**
  - approach velocities = 4, 6, 7.8 fps
- **water temperature and clarity**
  - did not report
- **results of test by species, velocity, screen porosity etc...**
  - coho display 100% diversion at all test conditions
  - some descaling occurs at 8 fps
  - no mortality observed

Mechanical

screen mesh design and porosity

graduated screen porosity

length (ft)	bar spacing (in.)	porosity (%)
20.0	0.125	63
7.5	0.035	32
7.0	0.008	8

screen length/exposure time

34.5 ft

screen angle

16.5°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

5.5 ft (66 in.) wide X 1.25 ft (15 in.) high rectangle leading to 2 ft pipe

maximum velocity of bypass flow

8 fps

bypass to screen approach velocity ratio

numerous tested (4:4; 6:4; 6:6; 7.8:7.8)

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- only preliminary results were given in this report comprised of figures and tables
- no detailed results were published
- other information pertaining to behavioral diversion techniques is presented (e.g., mercury lights, strobe lights, hammer)

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 12
Author: Taft, E.P., S.V. Amaral, F.C. Winchell, and C.W. Sullivan
Year: 1993
Title: Biological evaluation of a modular fish diversion screen.
Conference Name: Fish passage policy and technology: proceedings of a symposium.
Editor: K. Bates
Publisher: Bioengineering Section American Fisheries Society
Conference Location: Portland, Oregon.
Pages: 177-188
Abstract: The Electric Power Research Institute has developed and biologically evaluated a new type of fish diversion screen known as the Modular Inclined Screen (MIS). The MIS is designed to operate at any type of water intake with water intake up to 3.05 m/s (10 fps). The biological evaluation of the MIS was conducted with juveniles of 11 species, including four resident freshwater species, two alosid species, and five salmonid species. Fish passage was evaluated at five module velocities ranging from 0.61 to 3.05 ms^{-1} (2-10 fps). Except for alosids, the percent of fish diverted live for each species exceeded 95% at all module velocities. Latent mortality (72-hour; adjusted for control mortality) rarely exceeded 2% at test velocities up to and including 2.44 ms^{-1} (8 fps). Net passage survival (percent diverted live, adjusted for latent mortality) for all species tested (except alosids) was greater than 92.0% at module velocities of 2.44 ms^{-1} (8 fps) and less, and exceeded 99.0% overall for channel catfish (*Ictalurus punctatus)*, coho salmon (*Oncorhynchus kisutch)*, brown trout (*Salmo trutta)*, and Atlantic salmon (*Salo salar).* Fish passage tests with debris accumulation demonstrated that increases in screen head loss up to 12.2 cm (0.4 ft) did not reduce the ability of the MIS to safely and effectively divert fish, depending on species and module velocity.

DETAILED SUMMARY:

Lab or Field

Laboratory biological test of juveniles of 11 species in 1992 and 1993.

Biological or Hydraulic

Biological

species and size of test fish

1992
rainbow trout (48 mm)
rainbow trout (66 mm)
3 warmwater species

1993
coho (49 mm)
chinook (53 mm)
Atlantic salmon (169 mm)
brown trout (60 mm)
1 warmwater species

hatchery or wild
did not report

range of velocities tested
0.61 m/s (2.0 fps); 1.22m/s (4.0 fps); 1.83 m/s (6.0 fps);
2.44 (8.0 fps); 3.05 m/s (10.0 fps)

water temperature and clarity
did not report

results of test by species, velocity, screen porosity etc...

1992 percent diverted live

test velocity	2.0 fps	4.0 fps	6.0 fps	8.0 fps	10.0 fps	total
rainbow trout (48 mm)	98.5	100	100	95.2	95.6	97.7
rainbow trout (66mm)	100	100	100	99.1	96.3	99.1

1993 percent diverted live

coho (49 mm)	100	100	100	99	100	99.6
chinook (53 mm)	100	100	100	99.7	96.3	98.5
Atlantic salmon (169 mm)	100	100	100	100	100	100
brown trout (60 mm)	97.9	100	100	98.8	98.6	99.1

1992 percent adjusted latent mortality

test velocity	2.0 fps	4.0 fps	6.0 fps	8.0 fps	10.0 fps	total
rainbow trout (48 mm)	6.0	0.0	0.0	0.0	3.8	0.9
rainbow trout (66mm)	0.0	0.8	0.0	0.2	6.7	1.7

1993 percent adjusted latent mortality

coho (49 mm)	0.0	0.0	0.0	0.0	0.7	0.1
chinook (53 mm)	0.0	0.0	0.7	1.7	2.6	1.3
Atlantic salmon (169 mm)	0.0	0.0	0.0	0.0	0.0	0.0
brown trout (60 mm)	4.4	0.0	0.2	0.0	0.0	0.0

1992 percent net passage survival (survival adjusted for latent mortality)

test velocity	2.0 fps	4.0 fps	6.0 fps	8.0 fps	10.0 fps	total
rainbow trout (48 mm)	92.6	100	100	95.2	91.9	96.8
rainbow trout (66mm)	100	99.2	100	98.9	89.9	97.4

1993 percent net passage survival (survival adjusted for latent mortality)

coho (49 mm)	100	100	100	99	99.3	99.6
chinook (53 mm)	100	100	99.3	98	93.8	97.2
Atlantic salmon (169 mm)	100	100	100	100	100	100
brown trout (60 mm)	93.6	100	99.8	98.8	98.6	99.1

1992 percent adjusted injury rate (adjusted by control fish)

test velocity	2.0 fps	4.0 fps	6.0 fps	8.0 fps	10.0 fps	total
rainbow trout (48 mm)	1.4	0.0	0.9	0.8	2.0	1.0
rainbow trout (66mm)	1.7	1.6	0.0	0.0	1.9	0.6

1993 percent adjusted injury rate (adjusted by control fish)

coho (49 mm)	0.0	0.0	0.7	0.0	0.0	0.0
chinook (53 mm)	0.0	0.0	0.0	0.0	2.0	0.4
Atlantic salmon (169 mm)	0.0	18.9	0.0	0.0	0.0	4.0
brown trout (60 mm)	3.1	0.0	0.0	0.6	0.7	0.8

Mechanical

screen mesh design and porosity

wedge-wire with 1.9 mm openings and 50% porosity

screen length/exposure time

9.1 m long (29.86 ft) X 3.0 m wide (9.84 ft)
effective area = 23.2 m^2 (76.11 ft^2)

screen angle

15°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

did not report

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- 93.9% of all fish were recovered alive, 0.0% dead, and 6.1% impinged during debris testing (total recovered = 2,967)
- debris head loss was greater for deciduous leaves and aquatic vegetation than for equal weights of pine needles
- net passage of rainbow trout decreased to levels below 95% when head loss approached or exceeded 7.6 cm (0.25 ft) at 6 fps, becoming more dramatic with deciduous leaves and aquatic vegetation
- net passage of coho decreased to 73.8% when head loss approached or exceeded 7.6 cm (0.25 ft) at 6 fps
- net passage of chinook decreased to 90.0% when head loss approached or exceeded 7.6 cm (0.25 ft) at 6 fps
- 9,045 fish were recovered during non-debris (clean-screen) testing with 97.3% recovered alive, 0.3% dead, and 2.4% impinged
- prior to 1993 testing, an improvement (making the transition smoother) was made on the bypass that decreased impingements dramatically
- overall, adjusted injury rates were less than 5%
- generally, passage with low levels of debris was similar to passage success with a clean screen, however, passage with higher debris and higher levels of head loss decreased survival
- plans made to test a MIS at the Green island site

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 13
Author: Taft, E.P., F.C. Winchell, A.W. Plizga, E.M. Paolini, and C.W. Sullivan
Year: 1995
Title: Development and evaluation of the modular inclined screen (MIS).
Conference Name: Waterpower '95
Editor: J.J. Cassidy
Conference Location: San Francisco, California
Volume: 2
Pages: 1742-1751
Abstract: The Electric Power Research Institute (EPRI) has developed and biologically evaluated a new type of fish diversion screen know as the Modular Inclined Screen (MIS). The MIS is designed to operate at any type of water intake with water velocities approaching the screen of up to 3.1 m/s. The biological evaluation of the MIS was conducted in the laboratory with juveniles of eleven species. Fish passage was evaluated at five module velocities ranging from 0.6 to 3.1m/s. Net passage survival with a clean screen typically exceeded 99% at velocities up to 1. 8 m/s for most species, and exceeded 99% overall (all velocities combined) for channel catfish, coho salmon, brown trout, and Atlantic salmon. Fish passage tests with debris accumulation demonstrated that increases in screen head loss up to 12 cm did not reduce the ability of the MIS to safely and efficiently divert fish, depending on species and module velocity. On the basis of these results, EPRI, Niagara Mohawk Power Corporation (NMPC) and their contributors have constructed a prototype MIS at NMPC's Green Island Hydroelectric Project on the Hudson River. Field evaluations of this first MIS will be conducted in the fall of 1995. In addition to the MIS, the effectiveness of a strobe light system will be studied to determine its ability to divert blueback herring from the river to the MIS.

<u>DETAILED SUMMARY</u>:

Lab or Field
Laboratory biological test of juveniles of 11 species in 1992 and 1993.
Biological or Hydraulic
Biological
species and size of test fish
<u>1992</u>
rainbow trout (48 mm)
rainbow trout (66 mm)
3 warmwater species

1993
coho (49 mm)
chinook (53 mm)
Atlantic salmon (169 mm)
brown trout (60 mm)
1 warmwater species

hatchery or wild
did not report

range of velocities tested
0.6 m/s (1.97 fps); 1.2 m/s (3.94 fps); 1.8 m/s (5.91 fps);
2.4 (7.87 fps); 3.1 m/s (10.17 fps)

water temperature and clarity
did not report

results of test by species, velocity, screen porosity etc...

1992 percent net passage survival

test velocity	1.97 fps	3.94 fps	5.91 fps	7.87 fps	10.17 fps	total
rainbow trout (48 mm)	92.6	100	100	95.2	91.9	96.8
rainbow trout (66mm)	100	99.2	100	98.9	89.9	97.4

1993 percent net passage survival

coho (49 mm)	100	100	100	99	99.3	99.6
chinook (53 mm)	100	100	99.3	98	93.8	97.2
Atlantic salmon (169 mm)	100	100	100	100	100	100
brown trout (60 mm)	93.6	100	99.8	98.8	98.6	99.1

Mechanical

screen mesh design and porosity
wedge-wire with 2 mm openings and 50% porosity

screen length/exposure time
9.1 m long (29.86 ft) X 3.0 m wide (9.84 ft)
effective area = 23.2 m^2 (76.11 ft^2)

screen angle
15°

seal durability
did not report

screen design loading
did not report

Bypass/Penstock

volume of bypass flow relative to screen
did not report

maximum velocity of bypass flow
did not report

bypass to screen approach velocity ratio
did not report

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- debris tests were conducted, but debris was not quantified and results were grouped together with 93.9% recovered alive, 0.0% dead, and 6.1% impinged during debris testing (total recovered = 2,967)
- 9,045 fish were recovered during non-debris (clean-screen) testing with 97.3% recovered alive, 0.3% dead, and 2.4% impinged
- prior to 1993 testing, an improvement (making the transition smoother) was made on the bypass that decreased impingements dramatically
- overall, scale loss was less than 5%
- generally, passage with low levels of debris was similar to passage success with a clean screen, however, passage with higher debris and higher levels of head loss decreased survival
- plans made to test a MIS at the Green island site

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 14
Author: Taft, E.P., F.C. Winchell, S.V. Amaral, T.C. Cook, A.W. Plizga, E.M. Paolini, and C.W. Sullivan
Year: 1997
Title: Field evaluations of the new modular inclined fish diversion screen.
Institution: Presented at the Fish Passage Workshop.
City: Milwaukee, Wisconsin (in press) Waterpower `97, Atlanta Georgia.
Date: 6-8 May, 1997
Pages: 6
Abstract: A new type of fish diversion screen, known as the Modular Inclined Screen (MIS), is designed to provide fish protection at any type of water intake. Because the screen operates at water velocities of up to about 10 ft/sec (3 m/s) in the approach channel, the MIS is more compact and cost-effective than existing low velocity screens. A biological evaluation of the MIS was conducted in the laboratory with juveniles of eleven fish species. Net passage survival typically exceeded 99% at velocities up to 6 ft/sec (1.8 m/s) for most species, and exceeded 99% overall (all velocities combined) for four fish species. On the basis of these results, a prototype MIS was constructed and evaluated Niagara Mohawk Power Corporations Green Island Hydroelectric Project on the Hudson River. The prototype screen has a flow capacity of 150 cfs (4.2 m^3/s) at an approach velocity of 7.S ft/sec (2.3 m/s). Field evaluation of the MIS in 1995 and 1996 confirmed high rates of diversion and survival of juvenile rainbow trout golden shiners, largemouth bass and yellow perch, although lower survival was observed for the relatively fragile blueback herring. This paper presents the results of both the l995 and l996 field evaluation programs.

<u>DETAILED SUMMARY</u>:

Lab or Field
Field
Biological or Hydraulic
Biological
species and size of test fish
rainbow trout juveniles (94.7 mm)
hatchery or wild
did not report
range of velocities tested
0.61 m/s (2.0 fps); 1.22 m/s (4.0 fps); 1.83 m/s (6.0 fps);
2.44 (8.0 fps); 3.05 m/s (10.0 fps)
water temperature and clarity
did not report

results of test by species, velocity, screen porosity etc...

1992 percent net passage survival

test velocity	1.97 fps	3.94 fps	5.91 fps	7.87 fps	10.17 fps	total
rainbow trout (94.7 mm)	-	100	100	99.3	-	99.8

Mechanical

screen mesh design and porosity

50% porosity Hendrick profile bar with 2 mm spacing

screen length/exposure time

4.9 m long (16 ft) X 1.5 m wide (5 ft)

screen angle

15°

seal durability

seals were adequate to prevent fish passage and allow free movement of the screen during back washing

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

0.3 m (1 ft) entrance to bypass

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

screen was back washed at the end of each test

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- tests were conducted in late September and early November of 1995 and September in 1996
- no debris problems were noted, even after a large flood

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Video
Record Number: 15
Author: Triad Communications Ltd.
Year: 1994
Title: The Puntledge fishery reclamation project
Agency: Prepared for the British Columbia Hydro and Power Authority
City: Burnaby, British Columbia, Canada
Date: 21 January, 1994
Abstract: No abstract.

DETAILED SUMMARY:

Lab or Field
Summarization of the history of the Puntledge River project detailing the loss of spawning habitat for upstream migrant salmonids and the problems associated with downstream passage through the turbines. No specific details on screen design criteria are given.
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - coho
    - chinook
    - steelhead
  - **hatchery or wild**
    - did not report
  - **range of velocities tested**
    - did not report
  - **water temperature and clarity**
    - did not report
  - **results of test by species, velocity, screen porosity etc...**
    - 99% diversion from Comox Lake to the Puntledge River below the dam has been achieved through the application of an Eicher Screen.
- **Mechanical**
  - **screen mesh design and porosity**
    - did not report
  - **screen length/exposure time**
    - did not report
  - **screen angle**
    - did not report
  - **seal durability**
    - did not report
  - **screen design loading**
    - did not report

Bypass/Penstock

volume of bypass flow relative to screen

did not report

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- See Smith (1997) and Bengeyfield (1994; 1995) for detailed results.

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 16
Author: U.S. Army Corps of Engineers Seattle District
Year: 1997
Title: Draft Howard Hanson Dam additional water storage draft project feasibility study/environmental impact statement (Appendix D: hydrology and hydraulics).
Institution: Planning Branch (CENPS-EN-PL)
City: Seattle, Washington.
Pages: 54
Abstract: No abstract.

DETAILED SUMMARY:
Presentation of plans for a juvenile anadromous fish passage system for Howard A. Hanson Dam. The proposed passage system will consist of a modular inclined screen (MIS) chamber and a collector horn that float inside a grated wet well chamber. Included within this document are the selection process for the selected alternative design concept, the design of the proposed fish passage intake and outlet works, construction constraints, and the proposed hydraulic study requirements. The section of the report concerning high flow dewatering is similar to Zapel (1997).

Lab or Field
No tests were conducted

Biological or Hydraulic
Biological
species and size of test fish
not applicable
hatchery or wild
not applicable
range of velocities tested
not applicable
water temperature and clarity
not applicable
results of test by species, velocity, screen porosity etc...
not applicable

Mechanical
screen mesh design and porosity
wedge-wire [1/8 inch (3 mm) openings]
screen length/exposure time
16 ft wide X 30 ft long (410 ft screen area in fishing mode)
capacity of screen = 410 to 1600 cfs (2.56 to 10 fps)
velocity > 7.8 fps must be tested before it is allowable
screen angle
16°

seal durability

did not report

screen design loading

did not report

Bypass

volume of bypass flow relative to screen

bypass entrance = 2 ft X 2 ft leading to a
24 inch diameter low pressure bypass conduit
10 - 40 cfs (2.5% of MIS capacity) at 410 cfs and 1600 cfs screen discharge

maximum velocity of bypass flow

3.2 -12.4 fps through bypass (@ 410 cfs and 1600 cfs screen discharge)
2.5 fps -10 fps entrance velocity (@ 410 cfs and 1600 cfs screen discharge)

bypass to screen approach velocity ratio

normal velocity at screen (beyond near-screen orifice effects) =
1 fps (@ 410 cfs); 3 fps (@ 1250 cfs); 3.9 fps (@ 1600 cfs)

3.2:1 (@ 410 cfs screen discharge) - 12.4:3.9 (@ 1600 cfs screen discharge) bypass:normal screen velocity ratio

Debris loading

cleaning frequency

automatic rotation backflushes the screen when head loss exceeds 0.5 ft

duration of cycle

not applicable

timing of cycle (season)

not applicable

factors affecting load (reservoir size, watershed characteristics, elevation)

not applicable

Other:

- minimum capture velocity (5 fps) can’t be maintained for MIS at discharges less than 800 cfs without violating bypass entrance acceleration criteria
- acceptable fish survival rates at higher than 7.8 fps (1250 cfs) must be demonstrated before operation at higher velocities will be allowed

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 17
Author: U.S. Army Corps of Engineers Seattle District
Year: 1997
Title: Feasibility report and environmental assessment Wynoochee River fish restoration project.
City: Seattle, Washington.
Pages: 47
Abstract: No abstract.

<u>DETAILED SUMMARY</u>:

Lab or Field
Scoping document on a proposed fish bypass design developed during a series of meetings consisting of members of the technical review and advisory group. Testing has not been conducted, all information on the Eicher screen is in planning stages.
Biological or Hydraulic
No tests occurred.
Biological
target species and size of test fish
chinook
coho
steelhead
cutthroat
hatchery or wild
not applicable
range of velocities tested
not applicable
water temperature and clarity
not applicable
results of test by species, velocity, screen porosity etc...
not applicable
Mechanical
screen mesh design and porosity
58% porosity
screen length/exposure time
did not report
screen angle
16.5°
seal durability
did not report

screen design loading
did not report
Bypass/Penstock Criteria
volume of penstock flow relative to screen
200-650 cfs
minimum diameter = 10 ft
maximum velocity of penstock flow
8 fps (2.2 fps minimum with Eicher Screen in operation) in penstock

fish bypass discharge must be between 10 and 30 cfs (5-8 % of penstock flow)

fish bypass avg velocity must not exceed 10 fps or less than 4 fps
bypass to screen approach velocity ratio
did not report
Debris loading
cleaning frequency
cleaning required when head loss across screen is exceeded by 1.2 psi
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- The penstock wetwell as configured does not produce velocities sufficient to capture migrating smolts, because they are reluctant to sound to the depth necessary to be captured by penstock velocities. Capture velocities (>6 fps) are needed

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 18
Author: Wert, M.A., D.W. Casey, and R.E. Nece.
Year: 1987
Title: Hydraulic model evaluation of the Eicher passive pressure screen fish bypass system.
Institution: Prepared for the Electric Power Research Institute by Eicher Associates, Inc.
City: Palo Alto, California.
Date: October 1987
Type of Work: Final Report
Report Number: AP-5492 Project 1745-18
Pages: 88
Abstract: A hydraulic model of a passive pressure screen fish bypass system was evaluated at the University of Washington Harris Hydraulics Laboratory, Seattle, during 1984 and 1985. Stainless steel wedgewire screen inclined at 10.5, 16.5 or 30 degree to horizontal, was tested in a Plexiglass conduit. Velocity profiles were measured by pilot tube traverses. Dye tracers were also released to visually track the streamline patterns. Fish were monitored by video camera and recorder as they passed through the pressurized model. The screen angles, water velocities and screen types were varied. Scale loss was evaluated for smolted fish contacting the screen. Species tested included rainbow trout (*Salmo gairdneri)* and smolts of coho salmon (*Oncorhynchus kisutch*), chinook salmon (*0. tshawystcha*) and steelhead trout (*S. gairdneri*). Scale loss did not occur to coho, chinook or steelhead smolts which contacted the screen. No delayed mortality was observed within 72 hours after testing. All fish were successfully passed when velocities through the model were maintained at greater than 5 feet (1.5 m) per second. Small fish (fry size) passed through the model more swiftly than larger ones. Rainbow trout were used for impingement tests over a rage of test section velocities from 3.0 feet (0.9 m) to 10 feet (3 m) per second. Impingement was predictably produced or avoided by manipulation of velocities, and was most prevalent at test section velocities under 4 feet (1.2 m) per second. Variations in the velocity vector perpendicular to the screen did not affect fish passage over the range tested of 0.4 to 3.0 feet (0.1 to 0.9 m) per second.

<u>DETAILED SUMMARY</u>:

Lab or Field

laboratory model designed to:

- determine the hydraulic characteristics using a variety of screen types and flow angles
- evaluate fish passage in relation to behavior, scale loss, and impingement
- evaluate debris passage through the model

Biological or Hydraulic

Biological

species and size of test fish

rainbow trout
coho
fall chinook
steelhead

hatchery or wild

hatchery

range of velocities tested

variable velocities (3.0 - 8.8 avg test section velocity)
- descaling (> 40% descaled in 2 of 4 sections of the fish = 10% descaled) was tested at velocities of 5.8 and 7.5 fps, video cameras filmed the process, separating the fish into:
  - test fish, fish that touched the screen
  - control fish, fish that did not touch the screen

water temperature and clarity

48°F (9°C) - 53°F (11.7°C)

results of test by species, velocity, screen porosity etc...

species fork (cntrl)	length	avg vel	bypass vel	% descaled (cntrl)	72 hr mort
coho	134 mm	5.8 fps	7.9 fps	0.0 (0.0)	0.0 (0.0)
coho	134 mm	5.6 fps	7.6 fps	0.0 (0.0)	0.0 (0.0)
steelhead	199 mm	6.0 fps	7.0 fps	1.0 (0.0)	0.0 (0.0)
steelhead	199 mm	6.0 fps	6.9 fps	0.0 (0.0)	0.0 (0.0)
chinook	68 mm	6.0 fps	6.8 fps	1.0 (3.0)	0.0 (0.0)
chinook	68 mm	6.0 fps	6.9 fps	0.0 (0.0)	0.0 (0.0)

Mechanical

screen mesh design and porosity

wedge-wire screen with 2 mm bar and 2 mm continuous spacing

screen length/exposure time

7.7 ft (92 in) long X 6.25in wide

screen angle

16.5°

seal durability

neoprene gasket material

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

bypass opening = 3 in X 6.25 in rectangle

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

6.9:6.0 fps
7.9:5.8 fps
7.6:5.6 fps

Debris loading

cleaning frequency
did not report

duration of cycle
did not report

timing of cycle (season)
did not report

factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- the smallest fish, chinook, were swept through the model the most quickly and rarely made contact with the screen with adequate sweeping velocities
- coho were able to maintain position momentarily and briefly move upstream, 36% of which made contacting the screen once or twice with their tails
- steelhead, the largest test species, were able to maintain position for the longest time duration with approximately 82% coming in contact with the screen
- low average velocity through the screen (< 4 fps) and, more importantly, similar bypass velocities resulted in high rates of impingements (decreasing the sweeping velocity)
- all fish species tested tended to pass through the screen most effectively when water velocity was > 6 fps and bypass velocities exceeded that by 20%
- smaller fish run a greater risk of becoming impinged at threshold velocities
- the longer the fish were able to avoid being swept downstream, the greater the chance of becoming impinged
- Hendrick screen's more uniformly flat character results in better debris passage
- hydromer coating facilitated debris passage

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 19
Author: Winchell, F.C., and C.W. Sullivan
Year: 1991
Title: Evaluation of an Eicher fish diversion screen at Elwha Dam.
Conference Name: Waterpower'91
Editor: D.D. Darling
Conference Location: Denver, Colorado
Volume: 1
Pages: 93-102
Abstract: In the spring of 1990, the Electric Power Research Institute (EPRI) initiated testing of an inclined fish screen installed in a 9-foot diameter penstock at the Elwha Hydroelectric Project in Washington State. In tests performed with coho salmon smolts, over 99 percent of the fish were diverted without mortality. At penstock. velocities from 4 to 6 fps, less than 0. 1 percent of the fish had scale loss exceeding 16 percent on either side (considered "descaled" in criteria used on the Columbia River), and less than 5 percent showed any type of injury. Slightly more descaling was observed at higher penstock velocities. At the maximum velocity tested (7.8 fps), 3.6 percent of the fish had scale loss of over 16 percent, and 18.1 percent of the fish had scale loss between 3 percent and 16 percent. Mortality after a 3 to 10 day holding period averaged 0.21 percent for test fish and 0.14 percent for controls.

<u>DETAILED SUMMARY</u>:
This document summarizes the biological tests on coho during 1990. The same results plus 1991 biological testing and 1992 hydraulic testing are presented in the AFS and Waterpower papers released in 1993.

Lab or Field
Field
Biological or Hydraulic
Biological
species and size of test fish
coho 135 mm (5.3 in.)
hatchery or wild
hatchery fish reared in a net pen for 5 months in the Elwha forebay
range of velocities tested
1.22 m/s (4 fps) to 2.37 m/s (7.8 fps)
water temperature and clarity
did not report

results of test by species, velocity, screen porosity etc...

penstock:bypass ratio	% recovered	> 16% descaled	3-16% descaled	%latent mort.
4:4	99.6(test)	0.0	0.8	0.3
	100 (control)	0.0	1.2	0.0
4:6	99.2 (test)	0.0	1.4	0.2
	100.1 (control)	0.1	0.5	0.2
6:6	99.7 (test)	0.1	3.3	0.0
	99.9 (control)	0.0	0.5	0.1
6:7.8	99.9 (test)	0.0	4.1	0.3
	100 (control)	0.0	1.0	0.2
7:7	99.8 (test)	1.3	10.4	0.0
	99.7 (control)	0.0	0.8	0.3
7.8:7.8	98.8 (test)	3.6	18.1	0.3
	100.4 (control)	0.0	1.4	0.2
all conditions	99.5 (test)	0.8	6.3	0.2
	100.0 (control)	0.0	0.9	0.2

injury	n	no. mort.	% mortality rate
descaled (>16%)	46	4	8.7
scattered scale loss (3-16%)	202	0	0.0
patchy scale loss (3-16%)	184	2	1.1
other injuries	93	4	4.3
not descaled (<3%)	10,611	10	0.1
total	11,136	20	0.2

Mechanical

screen mesh design and porosity

length	bar spacing	bar width	porosity (%)
6.1 m (20.0 ft)	3.2 mm (0.125 in.)	1.9 mm (0.073 in.)	63
2.3 m (7.5 ft)	0.9 mm (0.035 in.)	1.9 mm (0.073 in.)	32
2.1 m (7.0 ft)	0.2 mm (0.008 in.)	2.4 mm (0.093 in.)	8

screen length/exposure time

10.5 m (34.5 ft)

screen angle

16.5°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

did not address, addressed in another paper

1.7 m (5.5 ft.) wide X 0.38 m (1.25 ft) high rectangle leading to 0.61 m (2 ft) pipe

0.71 m^3/s (25 cfs) = maximum flow tested

maximum velocity of bypass flow

did not address, addressed in another paper

2.62 m/s (8.6 fps)

bypass to screen approach velocity ratio

various ratios tested (1:1; 1.1:1; 1.3:1; 1.5)

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

in over 60 days of testing, debris accumulation over 8-12 hours did not cause an increase in injury rates

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- only coho smolts (101 - 165 mm) were tested in 1990, other fish species were recovered in good condition during the tests
  - steelhead (188 - 282 mm)
  - rainbow trout (53 - 122 mm)
  - sticklebacks (32 - 60 mm)
- little or no injury was observed under 6 fps approach velocities
- only 12 (test) and 8 (control) fish out of 5,000 (test) and 5,000 (control) died during the 3-10 day holding period
- head loss ranged from 15.2 cm (0.5 ft.) at 4 fps to 61 cm (2 ft) at 7.8 fps

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 20
Author: Winchell, F. , N. Taft, T. Cook, and C. Sullivan.
Year: 1993
Title: EPRI's evaluation of the Elwha Dam Eicher screen and subsequent design changes and hydraulic tests.
Conference Name: Fish passage policy and technology: proceedings of a symposium.
Editor: K. Bates
Publisher: Bioengineering Section American Fisheries Society
Conference Location: Portland, Oregon.
Pages: 186-196
Abstract: The Electric Power Research Institute (EPRI) has conducted two years of biological evaluations of an Eicher Screen installed in a 9-foot (2.7 m) diameter penstock at the Elwha Hydroelectric Project in Washington state. Testing has shown passage survival to equal or exceed 98.7% for steelhead trout (*Oncorhychus mykiss)* smolts and coho salmon (*0. kisutch)* and chinook salmon (*0. tshawytscha)* smolts and fingerlings. Scale loss injuries were minimal at velocities of 4-6 fps, but increased at higher velocities. Most injuries occurred from fish contacting the screen in an area where it transitions from 63% porosity to 32% porosity wedgewire material, where the velocity component perpendicular to the screen was relatively high. Hydraulic model studies conducted in 1992 indicated that a more gradual reduction of the porosity in the downstream end of the screen would reduce the observed velocity peak by approximately 10%, but would not achieve a fully uniform flow distribution.

<u>DETAILED SUMMARY</u>:
Summation of biological tests on three species of salmonids (1990 - 1991) and hydraulic model studies (1992 - 1993) to evaluate refinements to the screen’s design.
Lab or Field
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - steelhead 52 mm (2.0 in.) and 174 mm (6.9 in.)
    - coho 44 mm (1.7 in.), 135 mm (5.3 in.), and 145 mm (5.7 in.)
    - chinook 99 mm (3.9 in.) and 73 mm (2.9 in.)
  - **hatchery or wild**
    - hatchery
  - **range of velocities tested**
    - 1.22 m/s (4 fps) to 2.37 m/s (7.8 fps)
  - **water temperature and clarity**
    - did not report

results of test by species, velocity, screen porosity etc...

species	year	avg length	% avg diversion	% latent mort.	% net passage surv.
coho	1990	135 mm	99.5	0.1	99.4
coho	1990	102 mm	99.4	0.2	99.2
coho	1991	145 mm	98.7	0.0	98.7
coho	1991	44 mm	96.1	4.7	91.6
steelhead	1991	174 mm	99.6	0.2	99.4
steelhead	1991	52 mm	98.2	1.1	97.1
chinook	1991	99 mm	99.7	0.9	98.8
chinook	1991	73 mm	99.9	0.0	99.9

descaling (>16% scale loss on one side) for all species except chinook (99 mm)	avg penstock velocity
<1%	1.22 m/s (4 fps)
<1%	1.83 m/s (6 fps)
<2%	2.13 m/s (7 fps)
< 6%	2.38 m/s (7.8 fps)

Mechanical

screen mesh design and porosity

position	length	bar spacing	bar width	porosity (%)
inclined u/s	6.1 m (20.0 ft)	3.2 mm (0.125 in.)	1.9 mm (0.073 in.)	63
inclined d/s	2.3 m (7.5 ft)	0.9 mm (0.035 in.)	1.9 mm (0.073 in.)	32
bypass	2.1 m (7.0 ft)	0.2 mm (0.008 in.)	2.4 mm (0.093 in.)	8

screen length/exposure time

10.5 m (34.5 ft)

screen angle

16.5°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

1.7 m (5.5 ft.) wide X 0.38 m (1.25 ft) high rectangle leading to 0.61 m (2 ft) pipe

0.71 m^3/s (25 cfs) = maximum flow tested

maximum velocity of bypass flow

2.62 m/s (8.6 fps)

bypass to screen approach velocity ratio

various ratios tested (1:1; 1.1:1; 1.3:1; 1.5)

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

over 60 days of testing, debris accumulation over 8-12 hours did not cause an increase in injury rates

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- survival rates (up to 95%) can be achieved for fish at approach velocities up to 7 fps
- most or all of the injuries due to the screen happened on the transition between the 63 and 32% porosity sections where normal velocities > 3-3.5 fps when approach velocities > 7 fps
- injuries were rare when velocities were < 2.13 m/s (7 fps)
- noticeable head loss occurred when the screen was partially blocked with debris, which in turn increased injury rate
- latent (96 hr) mortality rate increases associated with scale loss varied by species

  steelhead (15.3% mort w/ 20-30% scale loss)

  chinook (2.8% mort w/ 30-40% scale loss)

  coho (1% mort w/ 50% scale loss)
- hydraulic tests indicated a more graduated reduction of screen porosity in the downstream end yielded the most uniform flow distribution and decreased normal velocity 10%
- uniform 50% porosity screen showed gradual increases in normal velocity
- head losses as small as 30 - 60 mm (0.1 - 0.2 ft) should be able to be detected by sensors

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 21
Author: Winchell, F., S. Amaral, N. Taft, and C. Sullivan.
Year: 1993
Title: Biological evaluation of a modular fish screen.
Conference Name: Waterpower '93
Editor: W.D. Hall
Conference Location: Nashville, Tennessee
Volume: 1
Pages: 328-327
Abstract: The Electric Power Research Institute (EPRI) has developed and is presently testing a new type of fish diversion screen known as the Modular Inclined Screen (MIS). The screen is designed to operate at high water velocities (up to 3.0 m/s) and is, therefore, significantly more compact than conventional low velocity screening systems. A biological evaluation of the MIS was conducted in 1992 with juveniles of six fish species: bluegill, walleye, rainbow trout, channel catfish, and two alosid species that were tested as one group. The results of this laboratory study demonstrate that the MIS has excellent potential for providing effective fish protection at water intakes.

DETAILED SUMMARY:

Lab or Field
Laboratory test using a 1:3.3 scale model for biological testing.
Biological or Hydraulic
Biological
species and size of test fish
rainbow trout fry (48 mm)
rainbow trout juveniles (66 mm)
five warmwater species (not debris tested)
hatchery or wild
did not report
range of velocities tested
0.6 m/s (2 fps); 1.2 m/s (4 fps); 1.8 m/s (6 fps); 2.4 m/s (8 fps); 3.0 m/s (10 fps)
water temperature and clarity
rainbow trout fry - 51-56 F
rainbow trout juveniles - 41-46 F

results of test by species, velocity, screen porosity etc...

percent of fish diverted alive

velocity	0.6 m/s;	1.2 m/s;	1.8 m/s;	2.4 m/s;	3.0 m/s
rbt fry	98.5	100	100	95.2	95.6
rbt juveniles	100	100	100	99.1	96.3

percent latent mortality (72 hr) of test fish and (control fish)

velocity	0.6 m/s;	1.2 m/s;	1.8 m/s;	2.4 m/s;	3.0 m/s
rbt fry	7.5 (1.6)	0.0 (0.0)	0.0 (3.3)	2.5 (2.6)	4.6(0.8)
rbt juveniles	0.9 (2.0)	0.8 (0.0)	0.0 (1.1)	1.9(1.7)	7.6(1.0)

Mechanical

screen mesh design and porosity

Hendrick profile bar screen; 1.9 mm spacing; 50% porosity

screen length/exposure time

did not report

screen angle

15°

seal durability

did not report

Bypass

volume of bypass flow relative to screen

flume flow capacity exceeded 2.83 m^3/s (100 cfs)

maximum velocity of bypass flow

3.0 m/s (10 fps)

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

tests were conducted with introduced debris

duration of cycle

most introduced debris was backflushed from the screen within 1 minute

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- At 0.4, 1.2, and 1.8 m/s, impingement did not occur at incremental head losses of less than 7.5 cm during the pine needle debris tests. Some impingement did occur at higher levels of headloss, but diversion efficiency generally remained above 90% at these velocities.
- At 2.4 m/s (8 fps)during debris test, diversion efficiency was comparable to a clean screen with headloss up to 1.5 cm, but efficiency decreased to 73% at head losses of 15 and 30 cm.
- 72-hour latent mortality was generally low up to 2.4 m/s (8fps) for rainbow trout and low for most species up to 1.8 m/s, even with high levels of debris.
- Fresh-fallen leaves (birch, oak, maple) and aquatic vegetation generally caused greater levels of headloss than pine needles at 1.8 m/s, but flushed completely from the screen.

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Conference Proceedings
Record Number: 22
Author: Winchell, F., N. Taft, T. Cook, and C. Sullivan.
Year: 1993
Title: Research update on the Eicher screen at Elwha Dam.
Conference Name: Waterpower '93
Editor: W.D. Hall, editor
Conference Location: Nashville, Tennessee
Volume: 1
Pages: 344-353
Abstract: The Electric Power Research Institute (EPRI) has conducted two years of biological evaluations of an Eicher Screen installed in a 9-foot (2.7 m) diameter penstock at the Elwha Hydroelectric Project in Washington state. Testing has shown passage survival to equal or exceed 98.7% for steelhead smolts, coho smolts, chinook smolts, coho fingerlings and chinook fingerlings. Scale loss injuries were minimal at velocities of 4-6 fps, but increased at higher velocities. Most injuries occurred from fish contacting the screen in an area where it transitions from 63% porosity to 32% porosity wedgewire material, where the velocity component perpendicular to the screen was relatively high. Hydraulic model studies conducted in 1992 indicated that a more gradual reduction of the porosity in the downstream end of the screen would reduce the observed velocity peak by approximately 10%, but would not achieve a fully uniform flow distribution.

<u>DETAILED SUMMARY</u>:
This paper is almost identical to the paper given at the American Fisheries Society fish passage policy and technology symposium. This document includes the summation of biological tests on three species of salmonids (1990 - 1991) and hydraulic model studies (1992 - 1993) to evaluate refinements to the screen's design.

Lab or Field

Biological or Hydraulic

- **Biological**
  - **species and size of test fish**
    - steelhead 52 mm (2.0 in.) and 174 mm (6.9 in.)
    - coho 44 mm (1.7 in.), 135 mm (5.3 in.), and 145 mm (5.7 in.)
    - chinook 99 mm (3.9 in.) and 73 mm (2.9 in.)
  - **hatchery or wild**
    - hatchery
  - **range of velocities tested**
    - 1.22 m/s (4 fps) to 2.37 m/s (7.8 fps)
  - **water temperature and clarity**
    - did not report

results of test by species, velocity, screen porosity etc...

species	year	avg length	% avg diversion	% latent mort.	% net passage surv.
coho	1990	135 mm	99.5	0.1	99.4
coho	1990	102 mm	99.4	0.2	99.2
coho	1991	145 mm	98.7	0.0	98.7
coho	1991	44 mm	96.1	4.7	91.6
steelhead	1991	174 mm	99.6	0.2	99.4
steelhead	1991	52 mm	98.2	1.1	97.1
chinook	1991	99 mm	99.7	0.9	98.8
chinook	1991	73 mm	99.9	0.0	99.9

descaling (>16% scale loss on one side) for all species except chinook (99 mm)	avg penstock velocity
<1%	1.22 m/s (4 fps)
<1%	1.83 m/s (6 fps)
<2%	2.13 m/s (7 fps)
< 6%	2.38 m/s (7.8 fps)

Mechanical

screen mesh design and porosity

length	bar spacing	bar width	porosity (%)
6.1 m (20.0 ft)	3.2 mm (0.125 in.)	1.9 mm (0.073 in.)	63
2.3 m (7.5 ft)	0.9 mm (0.035 in.)	1.9 mm (0.073 in.)	32
2.1 m (7.0 ft)	0.2 mm (0.008 in.)	2.4 mm (0.093 in.)	8

screen length/exposure time

10.5 m (34.5 ft)

screen angle

16.5°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

1.7 m (5.5 ft.) wide X 0.38 m (1.25 ft) high rectangle leading to 0.61 m (2 ft) pipe

0.71 m^3/s (25 cfs) = maximum flow tested

maximum velocity of bypass flow

2.62 m/s (8.6 fps)

bypass to screen approach velocity ratio
various ratios tested (1:1; 1.1:1; 1.3:1; 1.5)

Debris loading

cleaning frequency
did not report

duration of cycle
did not report

timing of cycle (season)
in over 60 days of testing, debris accumulation over 8-12 hours did not cause an increase in injury rates

factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- survival rates (up to 95%) can be achieved for fish at approach velocities up to 7 fps
- most or all of the injuries due to the screen happened on the transition between the 63 and 32% porosity sections where normal velocities > 3-3.5 fps when approach velocities > 7 fps
- injuries were rare when velocities were < 2.13 m/s (7 fps)
- noticeable, 25 - 50 mm (0.1 - 0.2 ft) head loss occurred when the screen was partially blocked with debris, which in turn increased injury rate
- latent (96 hr) mortality rate increases associated with scale loss varied by species
  steelhead (15.3% mort w/ 3-10% scale loss on one side)
  chinook (2.8% mort w/ 3-10% scale loss on one side)
  coho (1% mort w/ up to 30% scale loss)
- hydraulic tests indicated a more graduated reduction of screen porosity in the downstream end yielded the most uniform flow distribution and decreased normal velocity 10%
- uniform 50% porosity screen showed gradual increases in normal velocity
- head losses as small as 30 - 60 mm (0.1 - 0.2 ft) should be able to be detected by sensors

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 23
Author: Zapel, E.
Year: 1997
Title: Howard A. Hanson Dam juvenile fish bypass system
Institution: Presented at the Fish Passage Workshop
City: Milwaukee, Wisconsin.
Date: 6-8 May, 1997
Pages: 24
Abstract: A proposed juvenile anadromous fish bypass system was designed for Howard A. Hanson dam, a Corps of Engineers flood control dam located on the Green River in western Washington State. The bypass design was developed as part of a proposed water supply modification to the existing dam, in which the water supply reservoir behind the dam would be refilled each year to a higher level, providing for additional instream flows downstream of the dam during the summer low-flow period. Studies supporting the proposed water supply modification to date have included water supply reliability estimates for the increased water storage reservoir, fish and wildlife habitat improvement throughout the watershed upstream of the dam, and improved downstream migrant anadromous fish passage facilities. Currently, the dam operation plan does not include consideration of passage survival of downstream migrating anadromous fish originating from fry planted in the upper watershed. The existing outlet structures, while not entirely preventing fish passage, do cause considerable mortality and delay of downstream migrant fish. The proposed fish passage improvements are intended to dramatically improve passage survival and passage efficiency of the outlet structures and to provide eventual restoration of viable self-sustaining fish production for the upper watershed above the dam. The unique design for proposed fish passage facilities is the primary focus of this discussion.

DETAILED SUMMARY:
Presentation of plans for a juvenile anadromous fish passage system for Howard A. Hanson Dam. The proposed passage system will consist of a modular inclined screen (MIS) chamber and a collector horn that float inside a grated wet well chamber. This report is very similar to U.S. Army Corps of Engineers (1997).

Lab or Field

Biological or Hydraulic

No tests were conducted

Biological

species and size of test fish

not applicable

hatchery or wild

not applicable

range of velocities tested

not applicable

water temperature and clarity
not applicable
results of test by species, velocity, screen porosity etc...
not applicable

Mechanical

screen mesh design and porosity
wedge-wire [1/8 inch (3 mm) openings]
screen length/exposure time
16 ft wide X 30 ft long (410 ft screen area in fishing mode)
capacity of screen = 410 to 1600 cfs (2.56 to 10 fps)
maximum approved velocity = 7.8 fps 1250 cfs
screen angle
16°
seal durability
did not report
screen design loading
did not report

Bypass

volume of bypass flow relative to screen
bypass entrance = 2 ft X 2 ft leading to a
24 inch diameter low pressure bypass conduit
10 - 40 cfs (2.5% of MIS capacity) at 410 cfs and 1600 cfs screen discharge
maximum velocity of bypass flow
3.2 -12.4 fps through bypass (@ 410 cfs and 1600 cfs screen discharge)
2.5 fps -10 fps entrance velocity (@ 410 cfs and 1600 cfs screen discharge)
7.8 fps maximum until higher velocities are tested and approved
bypass to screen approach velocity ratio
normal velocity at screen (beyond near-screen orifice effects) =
1 fps (@ 410 cfs); 3 fps (@ 1250 cfs); 3.9 fps (@ 1600 cfs)
3.2:1 fps bypass:normal screen velocity ratio

Debris loading

cleaning frequency
automatic rotation backflushes the screen when head loss exceeds 0.5 ft
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- minimum capture velocity (5 fps) can't be maintained for MIS at discharges less than 800 cfs without violating bypass entrance acceleration criteria
- acceptable fish survival rates at higher than 7.8 fps (1250 cfs) must be demonstrated before the facility can be operated at higher velocities

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 24
Author: Sullivan, C.W.
Year: 1997
Title: Current hydropower research and development.
Institution: *In* Department of Energy, National Marine Fisheries Service, and Joan Harn editors. Hydropower research and development.
Date: 3 January, 1997
Report Number: DOE/ID-10575
Pages: 1
Abstract: The Modular Inclined Screen (MlS) has proven highly effective in diverting the early life stages of a wide variety of salmonid and non-salmonid fish species. It has the potential for wide-scale application at hydroelectric projects to reduce the existing losses of fish occurring as a result of turbine injury and mortality. A single module is designed to screen ~1000 cfs; additional modules are added to size a screening facility for a specific site.

Brief Description of Activity: Hydraulic and biological laboratory studies were conducted in 1992/1993 at Alden Research Laboratory, Inc. to develop and refine the initial design concept. Biological testing involved evaluation of the passage and survival of 11 species over a range of velocities from 2 to 10 ft/sec. A filed field evaluation of the MIS was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project in 1995/1996 with six species. In most cases, diversion efficiency approached 100%, injury rates were low, and latent survival was high. EPRI is currently pursuing commercialization of the screen in order to realize its full potential as a cost-effective fish protection concept.

<u>DETAILED SUMMARY</u>:
Brief summation of a hydraulic and biological tests modular inclined screen (MIS) at Alden Research Laboratory (1992 - 1993) and a biological evaluation at the Niagara Mohawk Corporation's Green Island Hydroelectric Project (1995 - 1996).
Lab or Field
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - did not report
  - **hatchery or wild**
    - did not report
  - **range of velocities tested**
    - 2 - 10 fps
  - **water temperature and clarity**
    - did not report
  - **results of test by species, velocity, screen porosity etc...**

In most cases, diversion efficiency has approached 100% with low injury rates and latent mortality.

Mechanical

screen mesh design and porosity

did not report

screen length/exposure time

did not report

screen angle

did not report

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

did not report

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- a single module can screen about 1000 cfs, with additional modules added to meet facility needs
- evaluation of the MIS technology is complete, efforts are now focused on commercialization of the screen

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 25
Author: Winchell, F.C., and E.P. Taft.
Year: 1992
Title: Evaluation of the Eicher Screen at Elwha Dam: 1990 and 1991 test results.
Institution: Prepared for Electric Power Research Institute by Stone and Webster Environmental Services.
City: Palo Alto, California.
Date: December 1992
Type of Work: Final Report
Report Number: EPRI TR-101704 Project 2694-1
Pages: 239
Abstract: In the spring of 1990, the Electric Power Research Institute (EPRI) initiated testing of a prototype inclined penstock ("Eicher") screen installed in a 9-foot diameter penstock at the Elwha Hydroelectric Project in Washington State. Results from the spring 1990 test program, presented in EPRI Report No. GS/EN-7036, showed that 99.4% of coho smolts (average length: 135 mm) were successfully diverted from the penstock and survived a 96-hour holding period (referred to as passage survival). A limited test program conducted with coho pre-smolts (average length: 102 mm) in the fall of 1990 showed a passage survival rate of 99.2%. The results of testing conducted in 1991, presented in this report, again showed high passage survival for coho smolts (98.7%, average length 145 mm), as well as steelhead smolts (99.4%, average length: 174 mm) and chinook fingerling smolts (98.8%, average length: 99 mm). Additional testing conducted with smaller salmonids also showed good passage survival for chinook pre-smolts (99.9%, average length: 73 mm), steelhead fry (97.1%, average length: 52 mm) and coho fry (91.6%, average length: 44 mm). Excluding tests conducted at penstock velocities of 7 fps or higher, the passage survival of coho fry was 95.9%.

Injuries were generally rare in tests conducted at penstock velocities of 7 fps or less. For all species and lifestages tested except chinook smolts, the proportion of fish with > 16% scale loss on one side ("descaled" as defined in criteria used on the Columbia River) averaged less than 1% at velocities of 4 and 6 fps, less than 2% at 7 fps, and less than 6% at 7.8 fps. Descaling was most common on chinook smolts, which averaged 0.4 % at 4 fps, 2.8 % at 6 fps, 6.7% at 7 fps and 12.6% at 7.8 fps. Most of the injuries appeared to be caused by fish contacting the screen in a localized area where the screen transitions from 63% to 32% porosity. Minor changes in the design of the screen were identified that could reduce or eliminate injury by providing a more even distribution of flow through the screen.

Injury rates increased substantially when the screen was partially clogged with introduced debris. However, the screen was readily cleaned by rotating it approximately 8 degrees. In over 60 days of testing performed at Elwha, natural debris accumulation over the 8 to 12 hour test periods never caused a noticeable increase in injury or necessitated cleaning of the screen.

Based on the high degree of success achieved at Elwha, the Eicher Screen appears to have great potential for application at other hydroelectric projects. The compact nature of the screen, which operates at relatively high water velocities, minimizes its aesthetic impact and may contribute to a substantial cost savings over conventional forebay screening systems in many applications.

DETAILED SUMMARY:
This paper is very similar to the papers given at the AFS fish passage policy and technology symposium and Waterpower `93. This document includes the summation of biological tests on three species of salmonids (1990 - 1991) and hydraulic model studies (1992 - 1993) to evaluate refinements to the screen's design. Results of the tests are much more detailed than in the other papers.

Lab or Field

Laboratory and field tests

Biological or Hydraulic

Biological

species and size of test fish

steelhead	52 mm (2.0 in.) and 174 mm (6.9 in.)
coho	44 mm (1.7 in.), 135 mm (5.3 in.), and 145 mm (5.7 in.)
chinook	99 mm (3.9 in.) and 73 mm (2.9 in.)

hatchery or wild

hatchery

range of velocities tested

1.22 m/s (4 fps) to 2.37 m/s (7.8 fps)

water temperature and clarity

turbidity was much higher in the fall 1990 tests

year	season	Secchi disk reading
1990	spring	10 ft
1991	spring	10 ft
1990	fall	16 - 24 inches

results of test by species, velocity, screen porosity etc...

species	year	avg length	% avg diversion	% latent mort.	% net passage surv.
coho	1990	135 mm	99.5	0.1	99.4
coho	1990	102 mm	99.4	0.2	99.2
coho	1991	145 mm	98.7	0.0	98.7
coho	1991	44 mm	96.1	4.7	91.6
steelhead	1991	174 mm	99.6	0.2	99.4
steelhead	1991	52 mm	98.2	1.1	97.1
chinook	1991	99 mm	99.7	0.9	98.8
chinook	1991	73 mm	99.9	0.0	99.9

diversion efficiency = percent test fish recovered/percent control fish recovered

species	year	avg length	test fish released	No. recovered	% control fish recovered	div. effic.
coho	1990	135 mm	5636	5606	100	99.5
coho	1990	102 mm	4628	4597	99.9	99.4
coho	1991	145 mm	6116	6028	99.9	98.7
coho	1991	44 mm	649	620	99.4	96.1
steelhead	1991	174 mm	4615	4597	100	99.6
steelhead	1991	52 mm	299	292	99.4	98.2
chinook	1991	99 mm	6230	6197	99.8	99.7
chinook	1991	73 mm	474	468	99.8	99.9

adjusted mortality = test survival - control survival (survival = 1 - mortality)

species	year	avg length	% test fish 4-day mort	% control fish 4-day mort	% adjusted mort
coho	1990	135 mm	0.2	0.1	0.1
coho	1990	102 mm	0.3	0.1	0.2
coho	1991	145 mm	0.1	0.2	0.0
coho	1991	44 mm	5.6	0.9	4.7
steelhead	1991	174 mm	3.1	2.9	0.2
steelhead	1991	52 mm	2.4	1.3	1.1
chinook	1991	99 mm	2.0	1.1	0.9
chinook	1991	73 mm	0.2	1.2	0.0

descaling (>16% scale loss on one side)

all species except chinook (99 mm)	avg penstock velocity
<1%	1.22 m/s (4 fps)
<1%	1.83 m/s (6 fps)
<2%	2.13 m/s (7 fps)
<6%	2.38 m/s (7.8 fps)

Mechanical

screen mesh design and porosity

length	bar spacing	bar width	porosity (%)
6.1 m (20.0 ft)	3.2 mm (0.125 in.)	1.9 mm (0.073 in.)	63
2.3 m (7.5 ft)	0.9 mm (0.035 in.)	1.9 mm (0.073 in.)	32
2.1 m (7.0 ft)	0.2 mm (0.008 in.)	2.4 mm (0.093 in.)	8

screen length/exposure time

10.5 m (34.5 ft)

screen angle

16.5°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

1.7 m (5.5 ft.) wide X 0.38 m (1.25 ft) high rectangle leading to 0.61 m (2 ft) pipe

0.71 m^3/s (25 cfs) = maximum flow tested

maximum velocity of bypass flow

2.62 m/s (8.6 fps)

bypass to screen approach velocity ratio

various ratios tested (1:1; 1.1:1; 1.3:1; 1.5)

Debris loading

cleaning frequency

did not report

duration of cycle

did not report

timing of cycle (season)

in over 60 days of testing, debris accumulation over 8-12 hours did not cause an increase in injury rates

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- survival rates (up to 95%) can be achieved for fish at approach
velocities up to 7 fps
- most or all of the injuries due to the screen happened on the transition between the 63 and 32% porosity sections where normal velocities > 3-3.5 fps when approach velocities > 7 fps
- injuries were rare when velocities were < 2.13 m/s (7 fps)
- noticeable, 25 - 50 mm (0.1 - 0.2 ft) head loss occurred when the screen was partially blocked with debris, which in turn increased injury rate
- latent (96 hr) mortality rate increases associated with scale loss varied by species
  - steelhead (15.3% mort w/ 3-10% scale loss on one side)
  - chinook (2.8% mort w/ 3-10% scale loss on one side)
  - coho (1% mort w/ up to 30% scale loss)
- hydraulic tests indicated a more graduated reduction of screen porosity in the downstream end yielded the most uniform flow distribution and decreased normal velocity 10%
- uniform 50% porosity screen showed gradual increases in normal velocity
- head losses as small as 30 - 60 mm (0.1 - 0.2 ft) should be able to be detected by sensors as they cause noticeable increases in injury rates
- lighting the penstock significantly decreased injury rate 1 out of 16 times
- turbidity did not affect injury or diversion efficiency
- little injury or mortality was witnessed on resident-migrant fish
  - steelhead (>160 mm)
  - rainbow (< 160 mm)
  - dolly varden
  - sculpin
  - sticklebacks

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 26
Author: Taft, E.P.
Year: 1986
Title: Assessment of downstream migrant fish protection technologies for hydroelectric application.
Institution: Prepared for Electric Power Research Institute by Stone & Webster Engineering Corporation.
City: Palo Alto, California
Date: September 1986
Type of Work: Final Report
Report Number: EPRI AP-4711 Project 2694
Pages: 424
Abstract: Objectives of the study were to 1) evaluate the capability of existing or potentially effective fish protection systems to minimize the impacts of hydroelectric projects on downstream migrating fish, 2) to identify important biological and engineering criteria for successful application of fish protection systems and ascertain the extent to which these criteria limit the applicability of systems, and 3) to identify research, development and testing needs to improve the effectiveness, reduce costs and/or determine the applicability of the concepts which have not been fully evaluated to date.

Tasks performed to meet the project objectives included:

* An assessment of the current state-of-the-art of fish protection

* A comparative evaluation of these systems in terms of their optimal design/operational requirements, existing or potential biological effectiveness, engineering and/or biological advantages and disadvantages and the need for further development and testing

* A comparative assessment of protection systems based on engineering, biological and cost criteria

* Delineation of methods of proposed research and development studies

The assessment of fish protection systems indicated that no single protection system presently exists which is biologically effective, reliable from an engineering viewpoint, considered acceptable for general use by various fishery management agencies and of reasonable cost. Because of the current regulatory climate, ongoing fish restoration programs, and the concern for even small fish losses, hydro applicants should work closely with regulatory agencies from early in the licensing process to determine the need for fish protection and to identify the most cost-effective system for use at a specific site.

Based on a ranking, a number of fish protection systems, not already under investigation, were recommended for further study. Recommendations for studies include two barrier devices (bar racks and fixed screens) which have not been previously evaluated to any great extent, and the addition of lights (strobe and/or mercury) to three different diversion-type systems (louvers, other bypass systems and spillways) in order to improve or enhance existing system efficiencies.

DETAILED SUMMARY:

summary of information concerning the T.W. Sullivan Hydroelectric plant in Willlamette Falls, Oregon

Lab or Field

Biological or Hydraulic

Biological

species and size of test fish

salmonids

hatchery or wild

did not report

range of velocities tested

1.5 m/s (5 fps)

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

98% screening efficiency rate for salmonids
90% survival rate through the bypass for salmonids
some descaling taking place at that time

Mechanical

screen mesh design and porosity

wedge-wire 2 mm X 2 mm

screen length/exposure time

calculated at 21/cos19 = 22.2 ft

screen angle

19°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

flume = 6.4 m (21 ft) X 3.4 m (11 ft)

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

5:1.5

Debris loading

cleaning frequency

largely self-cleaning

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- this is just a brief review of the T.W. Sullivan Hydroelectric plant in Willlamette Falls, Oregon
- no specific survival or injury rates are discussed

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Journal Article
Record Number: 27
Author: Electric Power Research Institute
Year: 1997
Title: Compact fish screen makes the grade
Journal: Hydro Plant News
Volume: 1:Spring 1997
Pages: 1
Abstract:
Tests of a Modular Inclined Screen developed by EPRI's Hydro Target have shown that the MIS is highly effective at safely diverting several species of juvenile fish under field Niagara Mohawk Power Corp.'s Green conditions. The tests were conducted at Island hydro site on New York's Hudson River. As an added bonus, the compact, high-velocity fish screen appears to be considerably less costly that conventional low velocity screens. Full details are now available to Hydro Target funders in the new EPRI report Evaluation of the Modular inclined Screen (MIS) at the Green Island Hydroelectric Project: 1995 Test Results (TR-106498).

HOW THE SCREEN WORKS

The EPRI-patented MIS consists of a wedgewire screen set at a 15° angle to the flow within a modular structure; a bypass diverts migrating fish to a transport pipe or holding facility. The inclined screen, is mounted on a pivot shaft, can be easily tilted at a different angle to backflush debris. The module is completely enclosed and designed to operate at water velocities from 2-8 ft/s. The new screen is suitable for application at any type of water intake, and multiple MIS units can be installed at a water intake to provide fish protection at any flow rate. "Because of its compact design, the MIS costs less to build than traditional low-velocity screens," notes Target Manager Charles Sullivan. Site-specific conditions must always be taken into account, but an MIS generally costs an estimated $1200-3700/cfs, compared with $2000-8000/cfs for angled fixed screens and angled drum screens, and $10,000-30,000/cfs for wedgwire screens.

RAINBOWS AND BLUEBACKS

The MIS passed its 1995 field tests at Green Island with flying colors. Diversion and survival rates for juvenile rainbow trout and golden shiners approached 100% at velocities from 2-7.5 ft/s. juvenile blueback herring survival rates were up to 95%, although results indicated that passage of this fragile species should be limited to velocities at or below 4 ft/s. The field tests also used an array of strobe lights to help direct fish toward the MIS. A total of 6825 fish were tested under the program.

Field test host Niagara Mohawk had a keen interest in the outcome of the tests. "We have 74 hydro stations generating some 674 MW, and of those stations, 30 are up for relicensing in the so-called Class of '93", says Ed Paolini the Niagara Mohawk project designer responsible for the Green Island tests. "Niagara Mohawk is evaluating its fish diversion needs and alternatives on a site-by-site basis, and Green Island was important because we have an annual migration of blueback herring there." The utility has not yet calculated the effects of the MIS on Green Island's O&M.

The California Department of Water Resources, Empire State Electric Energy Research Corp., New England Power Co., and New York State Energy Research and Development Authority (NYSERDA) also sponsored the Green island tests, which were conducted by Stone & Webster Environmental Technology & Services and Alden Research Laboratory, Inc. (ARL).

At the conclusion of the EPRI field tests, Niagara Mohawk and NYSERDA decided to conduct additional fish passage tests at the Green Island MIS. These independent tests were also successful.

Target funders may call Target Manager Charles Sullivan (415) 855-8948, for information on EPRI's patented MIS design.

DETAILED SUMMARY:

Lab or Field
Field
Biological or Hydraulic
Biological
species and size of test fish
rainbow trout juveniles
golden shiner juveniles
blueback herring juveniles
hatchery or wild
did not report
range of velocities tested
2 - 7.5 fps
water temperature and clarity
did not report
results of test by species, velocity, screen porosity etc...

- rainbow trout and golden shiner diversion and survival rates approached 100% for velocities ranging from 2 - 7.5 fps
- blueback herring survival rates were as high as 95% although their fragile nature indicates that velocities should be $\leq$ 4.0 fps

Mechanical
screen mesh design and porosity
did not report

screen length/exposure time
did not report
screen angle
did not report
seal durability
did not report
screen design loading
did not report

Bypass/Penstock
volume of bypass flow relative to screen
did not report
maximum velocity of bypass flow
did not report
bypass to screen approach velocity ratio
did not report

Debris loading
cleaning frequency
did not report
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- a small report on some of the findings of the Green Island MIS
- EPRI TR-106498 3572-01 contains a detailed summary of the 1995 test results
- this report indicates that Niagara Mohawk and the New York State Energy Research and Development Authority (NYSERDA) conducted additional testing. A call to both entities (Ed Paolini-Niagara Mohawk and John Martin-NYSERDA) discovered that the aforementioned EPRI document was the only published report concerning the Green Island MIS tests.

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 28
Author: Amaral, S.V., F.C. Winchell, T.C. Cook, and E.P. Taft.
Year: 1994
Title: Biological evaluation of a modular inclined screen for protecting fish at water intakes
Institution: Prepared by Stone and Webster Engineering Company for the Electric Power Research Institute.
City: Palo Alto, California
Date: May 1994
Report Number: TR-104121 Research Project
Pages: 126
Abstract: This report presents the results of a 2-year biological evaluation of the Modular Inclined Screen (MIS). The MIS was developed by the Electric Power Research Institute (EPRI) and is one of several fish protection technologies that EPRI has been investigating for application at water intakes. The MIS is designed to be applicable to all types of water intakes. Multiple MIS units can be installed at a water intake to provide fish protection at any flow rate.

The MIS consists of an entrance with trash racks, dewatering stop log slots, an inclined wedgewire screen set at a shallow angle (15°) to the flow, and a bypass for directing diverted fish to a transport pipe. The screen is mounted on a pivot shaft so that it can be cleaned by backflushing. The module is completely enclosed and is designed to operate at water velocities ranging from 2 to 10 ft/s (0.61 to 3.05 m/s), depending on the species and life stages to be protected. The screen in a prototype would be approximately 10 feet (3.3 m) wide by 31 feet (9.4 m) long, and would be capable of screening up to 800 cfs at a velocity of 10 ft/s (3 m/s). Guide walls, which slope inward at an angle of 20° over the downstream third of the screen, lead to the 2 x 2 ft (0.6 x 0.6 m) bypass entrance.

The initial MIS concept was refined during hydraulic studies conducted at the Alden Research Laboratory, Inc. (ARL) in Holden, Massachusetts. These studies showed that the MIS entrance design created an acceptable velocity distribution even when approach flows were skewed by as much as 45 degrees. Graduating the porosity of the screen or baffling were not required, since the modular design features were effective in developing uniform velocities over the screen surface without any high velocity zones.

Based on the results of the hydraulic studies, a 1:3.3 scale test facility was constructed at ARL for biological evaluation of the MIS. The MIS biological study examined the passage success of bluegill, walleye, channel catfish, juvenile alosids (blueback herring and American shad), golden shiners, rainbow trout (two size classes), coho salmon, chinook salmon, Atlantic salmon smolts, and brown trout. With the exception of Atlantic salmon smolts, the mean fork lengths of species tested ranged from 47 mm (1.9 inches) to 88 mm (3.5 inches). The mean fork length of Atlantic salmon was approximately 170 mm (6.7 inches). Tests with rainbow

trout fry, coho salmon, chinook salmon, golden shiners, and Atlantic salmon were conducted under clean screen and debris accumulation conditions. Debris tests evaluated fish passage at incremental screen head losses caused by the accumulation of debris which was introduced upstream of the MIS. Also, a series of tests with brown trout evaluated the effects of reduced bypass velocities on fish passage. Control groups were used to separate mortality and injury due to handling and testing procedures from that due to MIS passage.

The ability of the MIS to effectively divert fish was evaluated by determining diverted live and latent mortality and injury due to screen passage (i-e., adjusted for control mortality and injury). Test fish were released in the test flume through a pressure injection system. Test fish diverted by the screen were directed through a bypass and into a collection pen placed below a weir that controlled the bypass flow. Control fish were released directly into the collection pen. Colored ink marks or fin clips were used to distinguish between test and control fish. After all fish were collected, each one was checked for injury and scale loss and measured for fork length. All fish were held for 72 hours to assess latent mortality. Generally, for each species evaluated, three replicates were conducted at module velocities of 2, 4, 6, 8, and 10 ft/s (0.61, 1.22, 1.83, 2.44, and 3.05 m/s) during clean screen tests; a single test was conducted for each incremental head loss tested (up to 7 per velocity) during debris tests.

After the first series of tests was conducted in 1993 with coho salmon, it was noted that fish impingements occurred primarily on the screen edges along the transition walls approaching the bypass. A review of mapped impingements for 1992 tests revealed the same trend. Overall, an estimated 82.5% of recorded impingements occurred along the transition wall screen edges. In an attempt to reduce impingements along these screen areas, a 0.5-inch (1.3-cm) wide strip of the screen was blocked along the transition wall screen edges. Subsequent to this modification, the number of impingements observed were reduced substantially.

Under clean screen conditions, the percent diverted live was at or near 100 % for most species tested in 1992 at test velocities of 6 ft/s (1. 83 m/s) or less and for all species and velocities (2 to 10 ft/s [0.61 to 3.05 m/s]) tested in 1993. During the 2-year study, percent diverted live was 100% for 6 of the species tested at 2 ft/s (0.61 m/s), nine of the species tested at 4 ft/s (1.21 m/s), and 7 of the species tested at 6 ft/s (1.83 m/s). In most cases where the diversion efficiency at 2 ft/s (0.61 m/s) was less than 100%, this result could be attributed to fish mortalities related to collection technique (fish generally did not exit the bypass channel at 2 ft/s [0.61 m/s], and were subject to injury when dipnetted from the plexiglass bypass channel). Except for alosids, the percent of fish diverted live was greater than 95.0 % for all species tested at 8 and 10 ft/s (2.44 and 3.05 m/s).

The adjusted latent mortality was low for most species (typically less than 3.0% and often 0.0%). Isolated latent mortality (i.e., observed during only one replicate of a three-replicate series) occurred with several species and was greatest at 2 ft/s (0. 61 m/s) for three of the species tested. This indicates that handling procedures (e. g., marking/fm clipping, dipnetting from collection pen or bypass channel, and injury evaluation) may have contributed to the observed latent mortality of test fish.

Net passage survival (i.e., percent diverted live adjusted for latent mortality) exceeded 99% overall for 4 of the 11 species tested during the 2 years of study, and exceeded 97 % for 8 species. Passage survival generally exceeded 99% at velocities of up to 6 ft/s (1. 83 m/s), and generally exceeded 98% at 8 ft/s (2.44 m/s). Although passage survival of most species diminished at 10 ft/s (3.05 m/s), it still exceeded 98 % for 5 of the 11 species tested. Net passage survival would probably increase for the species tested in 1992, if they were tested with the new screen design (with flow blocked along the transition wall screen edges).

Adjusted injury rates for the majority of tests conducted in l992 and l993 were 0.0%. Golden shiners tested at 8 and 10 ft/s (2.44 and 3.05 m/s) and Atlantic salmon evaluated at 4 ft/s (1. 22 m/s) exhibited the only adjusted injury rates that exceeded 5. *0* %. Adjusted scale loss rates were low (< 2.0%) and the amount of scale loss seldom exceeded 3 to 10%. Injury rates remained fairly constant with increases in module velocity, however, golden shiner injury rates increased sharply at 8 and 10 ft/s (2.44 and 3.05 m/s).

The procedures used to collect and transport the juvenile alosids (blueback herring and American shad) testing during 1992 contributed to very high mortality rates and a substantial number of impingements due to the poor condition of the fish prior to testing. Testing with this species group was repeated during 1993 using improved collection and transport procedures. Despite the extra precautions taken in 1993, the latent mortality of both test and control groups for these species remained quite high. However, the immediate survival (percent diverted live) improved, particularly at the lower velocities, ranging from 99.8 % at 2 ft/s (0. 61 m/s) to 94.2 % at 6 ft/s (1.83 m/s). A second test series was conducted using a low-friction coating on the screen to find out whether the occurrence of impingements could be eliminated. Very little change in the percent of fish diverted live was noted using the low-friction coating. The percent diverted live ranged from 97.7% at 8 ft/s (2.44 m/s) to 82.5% at 10 ft/s (3.05 m/s).

A series of tests was conducted with brown trout at a module velocity of 6 ft/s (1.83 m/s) to examine the effects of reduced bypass flows on fish passage. The MS is designed to have bypass velocities equal to the module velocity; however, safe passage at lower bypass flows would mean less water would have to be diverted through the bypass. Bypass velocities of 3.0, 4.2, 4.8, and 5.4 ft/s (0. 91, 1.28, 1.46, and 1. 64 m/s; equivalent to 50, 70, 80, and 90% of the module velocity) were evaluated. Because brown trout was the only species and 6 ft/s (1.83m/s) the only module velocity to be tested with modified bypass flows, the results are considered preliminary in nature and may not hold true for other species and velocities.

The percent of brown trout diverted live was 100.0% at bypass velocities of 4.2, 4.8, and 5.4 ft/s (1.28, 1.46, and 1.64 m/s) and 97.1% at a bypass velocity of 3. 0 ft/s (0. 91 m/s). Latent mortalities (probably related to high water temperatures) resulted in slightly lower values for net passage survival, however, passage survival was still. greater than 99.0% at 4.2 and 4.8 ft/s (1.28 and 1.46 m/s). No injuries were observed during any of the tests conducted with modified bypass flows.

Four salmonid species and golden shiners were tested with debris accumulation on the screen. Rainbow trout fry were evaluated with three debris types (pine needles, deciduous leaves, and aquatic vegetation; tested separately); coho salmon, chinook salmon, Atlantic salmon, and golden shiners were tested with deciduous leaves. Test velocities ranged from 1.2 to 8 ft/s (0.37 to 2.44 m/s) and incremental head losses ranged from 0.01 to 1.3 ft (0.3 to 39.6 cm) depending on the species and debris type. Rainbow trout fry also were tested with residual debris on the screen after backflushing.

Debris-induced incremental head losses were greater for deciduous leaves and aquatic vegetation than for equal weights of pine needles. Also, screen head loss increased with module velocity for all three debris types. Head losses due to residual pine needles after backflushing ranged from 0.01 ft (0. 3 cm) at a module velocity of 2 ft/s to 0.18 ft at 8 ft/s (0. 61 m/s to 5.5 cm at 2.44 m/s). Deciduous leaf debris was completely flushed from the screen by backflushing, with no residual head loss observed. Residual head loss was estimated at 0.01 ft (0.3 cm) for aquatic vegetation.

Tests conducted with the three debris types indicated that passage success decreased as screen head loss increased to levels above 0.1 to 0.3 feet (3 to 9 cm), depending on species and test velocity. Above this level of accumulation, the percent diverted live and net passage survival for each species were typically lower for debris tests than they were for clean screen tests conducted at the same velocity, except for Atlantic salmon smolts for which these passage parameters were 100.0% at all incremental head losses and velocities tested (up to 0.5 ft at 6 ft/s and 0.4 ft at 8 ft/s [15 cm at 1.83 m/s and 12 cm at 2.44 m/s]).

Rainbow trout fry passage was evaluated with the three debris types (tested separately) at one module velocity, 6 ft/s (1.83 m/s). Net passage survival was similar (> 90.0 %) with all three debris types up to head losses of about 0.30 ft (9.1 cm); at greater head losses, passage survival dropped below 70.0% for tests with deciduous leaves and below 40.0% at a head loss of 0.80 ft (24.4 m) for tests with aquatic vegetation. During pine needle tests, the net passage survival of rainbow trout fry never reached levels below 89.0%, even at an incremental head loss level of 1.30 ft (39.6 cm).

Adjusted injury rates exceeded 0.0 % only twice for all debris tests conducted with rainbow trout fry. In 1993, the adjusted injury rates of salmonids were low (< 5.0%) at module velocities of 6 ft/s (1.83 m/s) or less. The adjusted injury rate of Atlantic salmon reached 23.5% at the highest incremental head loss tested (0.40 ft at 8 ft/s [12.2 cm at 2.44 m/s]). Golden shiner adjusted injury rates varied with velocity and head loss, although they were greatest for tests conducted at 8 ft/s (2.44 m/s).

The results of the MIS biological testing program clearly demonstrate that the MIS has excellent potential to effectively and safely divert a wide range of fish species at water intakes. During this study, the MIS successfully diverted fish to a bypass over a range of approach velocities (2 to 10 ft/s [0.61 to 3.05 m/s]) with minimal impingement, injury, and latent mortality. Also, debris accumulation tests determined that debris (pine needles, deciduous leaves, and aquatic vegetation) did not affect fish passage up to certain levels of debris-induced head loss.

DETAILED SUMMARY:

Lab or Field
Laboratory
Biological or Hydraulic
Biological
species and size of test fish
1993
coho [1.93 - 2.17 inches (49 - 55 mm)]
chinook [2.09 - 2.2 inches (53 - 56 mm)]
Atlantic salmon [6.65 - 6.85 inches (169 - 174 mm)]
brown trout [2.32 - 2.4 inches (59 - 61 mm)]
3 warmwater species
hatchery or wild
hatchery
range of velocities tested
2 - 10 fps (0.61 - 3.05 m/s)
water temperature and clarity
57 - 64 °F (14 - 18 °C)
results of test by species, velocity, screen porosity etc...

velocity (% diverted alive)

coho	2 fps (100)	4 fps (100)	6 fps (100)	8 fps (99.0)	10 fps (100)	total(99.6)
chinook	2 fps (100)	4 fps (100)	6 fps (100)	8 fps (99.7)	10 fps (96.3)	total(98.5)
Atlantic sal.	2 fps (100)	4 fps (100)	6 fps (100)	8 fps (100)	10 fps (100)	total(100)
brown trout	2 fps (97.9)	4 fps (100)	6 fps (100)	8 fps (98.8)	10 fps (98.6)	total(99.1)

percent latent (72 hour) mortality of test fish and (control fish)

velocity	2 fps	4 fps	6 fps	8 fps	10 fps	total
coho	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (2.0)	0.7 (0.0)	0.1 (0.4)
chinook	0.0 (0.0)	0.0 (2.0)	0.7 (0.0)	1.7 (0.0)	3.6 (1.0)	1.9 (0.6)
Atlantic sal.	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (1.4)	0.0 (0.0)	0.0 (0.3)
brown trout	6.3 (2.0)	0.0 (0.0)	2.3 (2.1)	0.0 (0.0)	0.7 (5.9)	1.6 (2.1)

Mechanical
screen mesh design and porosity
Hendrick profile bar screen (50% porosity)
screen length/exposure time
9.7 ft long
screen angle
15°
seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

0.8 - 4 cfs (0.02 - 0.11 m^3/s):16-80 cfs (0.45 - 2.27 m^3/s)

maximum velocity of bypass flow

bypass velocity = module velocity

10 cfs

bypass to screen approach velocity ratio

1:1

Debris loading

cleaning frequency

debris tests were conducted with incremental head losses ranging from 0.05 - 0.5 ft

duration of cycle

screen cycled after each test

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- This report summarizes research conducted at the Alden Research Laboratory, where three models were developed to examine the flow characteristics and biological effectiveness of the MIS. The first model involved the evaluation of the screen material and determine the effect of support bar configurations. The second model, a 1:6.66 scale, was used to examine head loss, bypass configuration, and screen velocity profiles. The third model, a 1:3.33 scale, was designed to conduct the biological evaluations. The 1992 biological test results appear in Winchell et al. (1993) review. The hydraulic test results were used during the design of the biological test model. This review concentrates on the 1993 biological test results.
- The screen was modified in 1993 by applying duct tape along the screen edges approaching the bypass, which coincided with the area of highest impingement. All test results reported in this review reflect the addition of duct tape.
- A test involving brown trout and reduced bypass velocities (< module velocities) revealed that bypass velocities of 50 to 90% of the module velocities do not negatively impact brown trout passage.
- Head losses up to 0.1 - 0.3 ft (3-9 cm) produced similar diversion and survival rates as clean screen tests., while injury rates during debris tests were low when module velocities were less than 6 fps.
- The report also contains the results of the hydraulic tests conducted on the MIS.

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 29
Author: Shiers, P.F., and E.P. Taft.
Year: 1996
Title: Evaluation of the modular inclined screen (MIS) at the Green Island hydroelectric project: 1995 test results.
Institution: Prepared by Stone & Webster Environmental and Alden Research Laboratories Inc. for the Electric Power Research Institute.
City: Palo Alto, California
Date: May 1996
Report Number: TR-106498 3672-01
Pages: 116
Abstract: This report presents the results of the biological testing conducted in 1995 by the Electric Power Research Institute (EPRI) to evaluate a prototype Modular Inclined Screen (MIS) installed at Niagara Mohawk Power Corporation's (NMPC) Green Island Hydroelectric Project in New York State. The MIS is a fish diversion screen designed to operate at high water velocities, resulting in a compact structure that typically would be less expensive to construct than conventional, low-velocity screening systems. The design was developed by EPRI during hydraulic model studies and biological testing conducted at the Alden Research Laboratory, Inc. in 1992 and 1993. Laboratory tests were conducted in a 1:3.3 scale test facility using juvenile bluegill, walleye, channel catfish, juvenile alosids (blueback herring and American shad), golden shiners, rainbow trout (two size groups), coho salmon, chinook salmon, Atlantic salmon smolts, and brown trout. The tests indicated that fish passage success approached 100% at velocities of up to 6 ft/sec (1.8 m/s) for nearly all species, with high passage and survival rates extending up to 8 or 10 ft/sec (2.4 or 3.0 m/s) for some species (EPRI 1994).

Based on the encouraging results obtained in the small-scale laboratory studies, EPRI offered to co-fund installation and testing of a prototype MIS to evaluate the effectiveness of a larger-scale MIS in passing fish under field conditions. Niagara Mohawk Power Corporation offered the Green Island Hydroelectric Project as a host site. An existing ice sluice gate at the site offered a feasible means to control flow rates through the prototype MIS. Furthermore, a fall outmigration of alosid species (primarily blueback herring) offered the opportunity to assess the effectiveness of the MIS in passing these relatively fragile fish under field conditions.

In 1992 and 1993, pilot studies were conducted at the Green Island Hydroelectric Project to assess the potential for evaluating the passage success of blueback herring using an MIS installed at the ice sluice gate. Passage routes utilized by outmigration blueback herring were recorded using side-scan sonar and the feasibility of using strobe lights to guide herring towards the MIS was evaluated. These studies indicated that herring approached the project along both sides of the forebay, and that fish observed on the side-scan sonar showed a strong avoidance response to strobe lights. Based on these results, the MIS test facility was designed

for installation in front of the ice sluice gate together with an array of strobe lights to guide outmigrating herring towards the entrance of the MIS.

The Green Island MIS was designed by Stone & Webster Environmental Technology & Services (Stone & Webster). The MIS was fabricated by Steel-Fab Inc. and installed by Steel Style Inc. at NUTC's Green Island Hydroelectric Project during the summer of 1995. The MIS test facility was located adjacent to the U.S. Army Corps of Engineers' dam and auxiliary spillway on the Hudson River, just north of Albany, New York. The inclined screen was sloped upwards at a 15-degree angle and served to guide fish towards a bypass at the top of the water passageway. The screen was composed of panels of profile bar (commonly referred to as wedgewire) material with a uniform porosity (open area) of 50%. The screen design was selected based on the results of laboratory model tests.

One season of testing has been performed at the Green Island site. Although there are improvements and refinements that could be incorporated into future MIS facilities, whether they are temporary test facilities or permanent downstream fish passage facilities, the Green Island MIS satisfactorily met its design and operational requirements.

Hydraulic testing at Green Island indicated that the test facility can operate at approach velocities ranging between 2.0 and 7.5 ft/sec (0.6 and 2.3 m/s) at the normal forebay water level (El. 16.3 ft (5-0 m)). The operating range was determined by the hydraulic capacity of an existing ice sluice gate which was used to control flow through the MIS. Velocity measurements indicated that the screen face velocity profile at Green Island is consistent ' with the model study results. A low-velocity area near the MIS roof, attributed to the presence of an isolation screen and gate in the MIS screen approach area (not present in the model), was identified at Green Island. Total head losses created by the MIS components ranged between 0.1 ft (3 cm) at a 2 ft/sec (0-6 m/s) module velocity up to 2.2 ft (0.7 m) at a 7.5 ft/sec (2.3 m/s) module velocity.

The biological test program at Green Island had several key objectives. These included determining whether increasing the size of the screen and/or debris conditions in a riverine application would impact fish passage success. These two objectives were addressed by conducting passage tests using juvenile golden shiners and rainbow trout, species which had been tested successfully in the laboratory. The other key objective was to evaluate passage survival of blueback herring, a species which suffered high mortality of both test and control fish during the laboratory studies. High control mortality indicated that this relatively fragile species was stressed and/or injured during collection, transport and handling, precluding a conclusive assessment of passage survival in the laboratory.

Golden shiners and rainbow trout were introduced into the MIS passageway just upstream of the screen using a pressurized air injection system. In order to minimize stress and injury to the herring, the test plan focused on evaluating passage success for herring that entered the MIS of their own volition. An array of strobe lights was provided to guide outmigrating herring into the entrance of the MIS. The strobe array was set at an upstream angle from the MIS entrance, and spanned approximately half of the width of the forebay.

Biological testing was initiated in late September 1995, starting with injection testing of golden shiners and operation of the facility during times of peak migration activity to collect blueback herring that entered the MIS of their own volition. During the first 2 weeks of testing, the golden shiner injection tests were completed, but relatively few collections of naturally-entrained herring had resulted in insufficient sample sizes for assessment of passage survival. Review of continuously-recorded data from side-scan sonars indicated that most of the outmigrating herring were passing along the west shore of the forebay where they were not intercepted by the strobe array. In addition test results indicated that long test durations were contributing to injury of fish in the hopper used to collect fish diverted by the MIS. In order to increase the amount of data obtained for herring and to control the time that fish were exposed to the collection hopper, a series of blueback herring injection tests was conducted.

As evidenced by scanning sonar data and gull feeding activity below the dam, most of the herring outmigration occurred during a high flow event which occurred on October 15-17, 1995. During this time, testing was constrained by headpond levels higher than the allowable test range. The headpond level was brought down into the allowable testing range for several hours each day by deflating a rubber dam, sacrificing generation but allowing testing to continue. During this period, test fish were collected at night from the forebay using a lift net and injection tests were conducted during the day when the rubber dam could be lowered.

The abundance of herring available for testing declined after a major flood occurred on October 22-30, essentially ending the 1995 outmigration. Following the flood, the facility was returned to operational status and rainbow trout injection tests were completed on November 2-3, 1995.

Excellent results were obtained during the golden shiner and rainbow trout injection tests, with diversion efficiency and survival approaching 100% over the full range of velocities tested (2 to 7.5 ft/sec (0.6 to 2.3 m/s)). These results were comparable to those obtained during laboratory testing, indicating that the larger size of the Green Island screen and the presence of debris did not adversely affect passage success. The data suggests that the high passage survival rates observed for many species during the laboratory testing program should be attainable in full-scale applications of the MIS. The average length of the golden shiners and rainbow trout tested was 71 and 95 mm (2.8 and 3.7 in.), respectively.

The limited amount of data obtained for naturally-entrained blueback herring indicated that-scale loss injuries increased and survival rates decreased at higher velocities. It was determined that much of this injury occurred during collection in the hopper, but low fish collection rates made it impossible to control the duration that naturally-entrained fish were exposed to in the hopper. Injection tests allowed the exposure time in the hopper to be controlled, but it is suspected that releasing the fish in close proximity to the screen face presented a worst-case scenario that contributed to the level of injury observed. Blueback herring survival rates adjusted for control mortality ranged from 95% at 2 ft/sec (0.6 m/sec) to 27% at 6 ft/sec (1.8 m/sec). The average length of the blueback herring tested was 61 mm (2.4 in.).

If additional testing of blueback herring at Green Island is conducted, consideration should be given to deploying a high frequency sound system on the west shore of the Green Island forebay in addition to the strobe lights. Based on past experience with sound at other sites, this system should be effective in diverting outmigrating herring towards the east side of the forebay where they would be intercepted by the strobe light array and the MIS. This approach would increase the rate of fish collection in the MIS, enabling more data to be collected and reducing collection injuries associated with long test times. In addition, several minor modifications of the collection hopper could be implemented to reduce injuries and improve test results.

DETAILED SUMMARY:

Lab or Field

Field test conducted on the Hudson River near Albany, New York.

Biological or Hydraulic

Biological

species and size of test fish

rainbow trout 2.1 - 4.8 inches (54 - 122 mm)
golden shiner
blueback herring

hatchery or wild

hatchery

range of velocities tested

2, 4, 6, or 7.5 fps (0.61, 1.22, 1.83, or 2.29 m/s)

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

species	**velocity (% diverted alive)**		
rainbow trout marked test fish	4 fps (100)	6 fps (100)	7.5 fps (100)
rainbow trout marked control fish	4 fps (100)	6 fps (100)	7.5 fps (100)
rainbow trout unmarked control fish	4 fps (100)	6 fps (100)	7.5 fps (100)

percent latent (48 hour) mortality

velocity	4 fps	6 fps	7.5 fps
rainbow trout marked test fish	0	0	0.7
rainbow trout marked control fish	0	0	0
rainbow trout unmarked control fish	0.4	0	1.4

Mechanical

screen mesh design and porosity

Hendrick Type B-6A 50% porosity

screen length/exposure time

16 ft (4.9 m)

screen angle

15°

seal durability

a rubber seal was provided around the periphery of the screen where it abutted with the MIS structure

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

approximately 20:1 based on poor velocity measurements

maximum velocity of bypass flow

turbulence did not allow for accurate velocity measurements in the bypass

bypass to screen approach velocity ratio

turbulence did not allow for accurate velocity measurements in the bypass

Debris loading

cleaning frequency

natural debris accumulation was relatively low because of the submerged frequent backwashing should be considered if the MIS is installed in a riverine situation

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- In most cases, the results from the MIS installed at the Green Island facility on the Hudson River were similar to the results of previous laboratory studies.
- Mechanically, the MIS reseated properly when raised to the normal position even after a large flood inundated the entire facility.
- Biologically, rainbow trout diversion and latent survival rates were near 100% at velocities of 4, 6, and 7.5 fps. Velocities of < 4 fps were not attainable because of high pond levels.
- This report includes a description of construction related problems and site preparation techniques used during the installation.
- Numerous seals leaked after the installation, this along with other problems may have been remedied if the MIS was constructed and installed in the dry.

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 30
Author: Winchell, F.C., S.V. Amaral, and E.P. Taft.
Year: 1994
Title: Research update on fish protection technologies for water intakes.
Institution: Prepared by Stone & Webster Engineering Corporation for Electric Power Research Institute.
City: Palo Alto, California
Date: May 1994
Report Number: TR-104122
Pages: 208
Abstract: In 1986, the Electric Power Research Institute (EPRI) published a comprehensive review of available technologies for protecting downstream migrating fish, as well as resident fish, at hydroelectric facilities. Since that time, extensive research on fish protection has continued, and new protective devices have been installed at numerous sites. This report provides an update on the information base presented in the 1986 review. The report provides an overview of recent studies, organized by the following categories of fish protection technologies: behavioral devices, physical barriers, fish collection systems, and fish diversion devices.

A substantial amount of recent research has shown behavioral responses of fish to electrical fields, strobe light, mercury light, and sound generating devices that could be useful for guiding fish or excluding them from water intakes. Although few full-scale installations of behavioral devices have been tested successfully to date, the promising results obtained in many studies suggest that behavioral devices will be developed or incorporated into full-scale protection systems at many sites within the next decade. The most successful recent studies of behavioral devices have employed strobe lights or transducer-generated sound as means to repel fish.

Only a limited amount of recent research has been conducted on physical barriers. Studies conducted at the Pine site in Wisconsin, along with results from other sites reported in the 1986 EPRI Review, indicate that barrier nets can offer a cost-effective means to reduce fish entrainment, particularly at sites with limited debris and wave action. Coanda screens also appear to provide an effective barrier to fish entrainment at low-flow sites, but information on their effectiveness at protecting fish is lacking at this time. Cylindrical wedge-wire screens appear to offer good potential for protecting fish, but they are relatively costly for screening large water volumes, and definitive proof of their effectiveness for protecting fish at hydroelectric projects is not available at this time.

Modified travelling screen collection systems offer the only available means for protecting larval and early life stages of many species, but they are generally too costly for screening the large flow volumes required at hydroelectric installations. Recent research has resulted in

improvements in the design of modified traveling screens, particularly to eliminate vortices within the fish collection trough that can cause injury and/or mortality. Other research has identified improvements in screen components required for continual and/or high speed operation required for adequate fish protection. In addition, several recent papers have shown successful application of new types of fish pumps, including Archimedes and air-lift designs.

Many types of low-velocity screening systems have been installed in recent years. These facilities are usually designed such that the velocity component perpendicular to the screen does not exceed certain state or federal criteria (usually 0.33 to 0.5 ft/s). Testing of these types of screen systems has generally demonstrated low injury rates. However, since fish are generally able to maintain position within the screening facility or emigrate upstream, few studies have been able to conclusively demonstrate a guidance efficiency exceeding 90%. Although the effectiveness of these facilities are probably close to 100% at many sites, losses may occur at some sites from predation or leakage of fish past faulty or worn screen seals.

Recent research on high-velocity screening systems have demonstrated guidance and survival to exceed 99% for many species at velocities of up to 8 or 10 ft/s, and up to 3 ft/s measured perpendicular to the screen. As a result, these types of designs require as little as 10 % of the screen area required for low-velocity systems. Information available at this time indicate that these types of facilities can be constructed at most sites for approximately half the cost of low velocity screening systems. Limitations include increased head loss at higher velocities and the requirement for frequent cleaning at sites which entrain a significant debris load.

Louvers have been shown to achieve good guidance (> 85 %) for larger fish of most species and have been recently applied at Hadley Falls for diverting Atlantic salmon smolts and juvenile clupeids. Results obtained to date have been encouraging, particularly for salmon smolts.

The effectiveness of angled bar racks and close-spaced bar racks equipped with surface bypasses is an area where more biological evaluation is required. These types of protection systems have been installed to protect Atlantic salmon smolts and Alosids in the northeast and resident species in other regions. Many sites which have recently installed these types of devices have been required to monitor their effectiveness. As a result, more information on their effectiveness should become available within the next several years.

DETAILED SUMMARY:

Lab or Field
Review of water intake technology advancement that was reported in a 1986 review.
Biological or Hydraulic
Biological

species and size of test fish
not applicable
hatchery or wild

not applicable

range of velocities tested

not applicable

water temperature and clarity

not applicable

results of test by species, velocity, screen porosity etc...

not applicable

Mechanical

screen mesh design and porosity

not applicable

screen length/exposure time

not applicable

screen angle

not applicable

seal durability

not applicable

screen design loading

not applicable

Bypass/Penstock

volume of bypass flow relative to screen

not applicable

maximum velocity of bypass flow

not applicable

bypass to screen approach velocity ratio

not applicable

Debris loading

cleaning frequency

not applicable

duration of cycle

not applicable

timing of cycle (season)

not applicable

factors affecting load (reservoir size, watershed characteristics, elevation)

not applicable

Other:

- This document reviews the rotating inclined screens in place at the T.W. Sullivan Plant near Willamette Falls, Elwha Hydroelectric Project, and Puntledge Hydro Plant in British Columbia. In addition, laboratory studies involving rotating inclined screens at Harris Hydraulics Laboratory located at the University of Washington and Alden Research Laboratory in Holden, Massachusetts are included in the review.

- Sullivan Plant
  after refinements, the screen appears successful in passing chinook, steelhead, coho
- Elwha Hydroelectric Project

achieved successful passage of coho and chinook salmon

- Puntledge Hydro Plant
  achieved successful passage of coho and chinook salmon
- Harris Hydraulics Laboratory
  successful passage of rainbow trout, steelhead, coho, and chinook, especially at approach velocities > 5 fps
- Alden Research Laboratory
  studies underway in an attempt to refine the modular inclined screen (MIS) primarily for non-penstock applications appear to indicate that the MIS is successful in passing numerous species of fish including rainbow trout, coho and chinook salmon

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 31
Author: Taft, E.P., F.C. Winchell, S.V. Amaral, and T.C. Cook.
Year: 1994
Title: Fish protection/passage technologies evaluated by EPRI and guidelines for their application.
Institution: Prepared by Stone & Webster Engineering Corporation for the Electric Power Research Institute.
City: Palo Alto, California
Date: May 1994
Report Number: TR-104120
Pages: 203
Abstract: Protection of fish from entrainment-related mortality is an important issue at many hydroelectric projects and other water intakes including those used for irrigation, cooling water and municipal water supply. Existing technologies that have been proven to be effective rely primarily on large screening structures designed to provide a very low approach velocity. These facilities can be very expensive to construct, with total project costs usually in the range of $2,000 to $10,000 per cfs capacity. These approaches may not be cost-effective for many projects, particularly for low head projects that pass a large volume of flow relative to the amount of energy produced.

The Electric Power Research Institute (EPRI) has funded two major reviews of fish protection technologies. These reviews identified several potentially viable alternative technologies, including high-velocity screening systems, barrier nets and behavioral guidance devices. Over the past decade, EPRI has funded a number of studies to evaluate the effectiveness and limitations of these technologies. In addition, EPRI funded a recent review of trends in fish entrainment and mortality occurring at hydroelectric projects.

The intent of this report is to consolidate all available information regarding the alternative fish protection technologies evaluated by EPRI. The report draws relevant information from previous EPRI reports and other available sources. The following is a summary of the research funded by EPRI for each technology and the main advantages and limitations identified for each.

EPRI has been involved since 1984 in development and evaluation of the Eicher screen, designed to safely divert fish from enclosed penstocks. EPRI-funded research has included initial fish passage tests conducted at the Harris Hydraulics Laboratory during 1984-85, development and evaluation of a full-scale prototype during 1990-91 at the Elwha Hydroelectric Project, and hydraulic model studies conducted during 1992-93 at the Alden Research Laboratory, Inc. (ARL) to evaluate refinements to the Elwha design.

The studies conducted at the Harris Hydraulics Laboratory demonstrated that juvenile salmonids can be safely diverted using an inclined section of wedge-wire screen over a wide range of approach velocity conditions. Subsequent testing of the Elwha prototype demonstrated a survival rate exceeding 99% for the three target species of salmonid smolts, although limited testing conducted with smaller salmonids indicated lower survival rates, particularly at the higher velocities tested. The success of the Elwha test program led B. C. Hydro to install two full-scale Eicher Screens at the Puntledge hydro project, and initial testing of these screens also indicate survival rates exceeding 99%. The ARL model studies have identified several refinements to the design that should be considered in future applications.

The primary advantages of the Eicher screen over conventional low-velocity technologies include its small size (about 10% of the screen area required for conventional low-velocity screening systems), its relatively low cost (about 50% of the cost of low-velocity systems), minimal potential for delay and/or predation of fish passing through the screening facility, and the ability to rapidly and accurately determine the facility's effectiveness. The concept is particularly attractive for projects with deep intakes, where forebay screening may not be practical. The Eicher screen is also relatively invulnerable to icing problems, and experience to date indicates low O&M costs.

The primary disadvantages of the Eicher screen include head loss (ranging from about 0.5 feet at 4 feet per second to about 1.9 feet at 7.8 - feet per second, and diminished performance with the accumulation of debris on the screen. (However, testing has indicated that most types of debris can be readily removed from the screen via tilting and backflushing.) To date, only limited data is available on the screen's effectiveness with smaller fish and non-salmonid species. These factors currently limit the acceptance of the Eicher screen by resource agencies, particularly at sites where endangered species occur.

EPRI undertook a research program starting in 1991 to develop the Modular Inclined Screen (MIS). The MIS applies the high-velocity screening concept in a modular form that is suitable for nearly any type of water intake. The modular approach allowed development of a standardized design that can be applied for a facility of any flow rate by adjusting the number of modules. Use of the design should reduce the engineering and evaluation requirements for future installations.

The MIS development program was comprised of three phases including evaluation of near-field flow patterns in a small test flume, evaluating the hydraulics of the structure in a 1:6.6 scale model, and biological testing conducted in a 1:3.3 scale test facility. All three models were constructed and tested at ARL.

The hydraulic model studies resulted in development of a design which exhibited a very uniform flow distribution along the entire length of the inclined screen. Biological testing performed with ten different species of fish indicated that diversion and survival rates exceeding 99% could be achieved for most species over a wide range of velocities (up to 10 feet per second for some species). Velocities of up to 6 feet per second resulted in excellent survival for nearly all of the species tested, which ranged in size from 47 to 173 mm.

The MIS offers all of the advantages listed above for the Eicher screen. The more uniform flow distribution compared to the Eicher screen will probably enhance the ability of the MIS to successfully pass fish over a wider range of velocities and may facilitate passage for a wider range of fish species and size ranges. Furthermore, the modular design allows the MIS to be applied at nearly any type of water intake. Installation of multiple modules also allows considerable operational flexibility, including the ability to perform maintenance on individual modules without interrupting generation.

The limitations of the MIS are essentially the same as those of the Eicher Screen. Head loss is likely to be comparable to the Eicher screen, as is the necessity for periodic flushing of debris from the screen. At installations with multiple modules, the potential exists to reduce flow through individual units during flushing to reduce the number of fish that may move past the screen. Installation of a barrier screen during this procedure could eliminate the potential for losses of fish past the screen.

The performance of previous and existing barrier net installations was summarized in the two EPRI review documents. During 1990-91, EPRI co-funded a study with the Wisconsin Electric Power Company (WEPCO) to evaluate a barrier net installed at the Pine hydro project. The study at Pine concluded that barrier nets can provide a cost-effective means to reduce fish entrainment. The Pine study indicated that entrainment was reduced by at least 77%, and mark recapture studies indicated an effectiveness of 100% when the net was deployed fully to the water surface. Operational experience indicated that the net design used at Pine had a service life of at least 5 years. The success of the Pine study has led WEPCO to propose reinstallation of the net in 1995 as a long-term means to minimize entrainment at the Pine site.

The primary advantage of a barrier net approach is its relatively low cost (probably less than 10% of the cost of most other alternatives). Limitations include reduced effectiveness and increased maintenance costs at sites with high water velocities, high debris loads, or substantial wave action. Barrier nets have generally not been applied in situations where downstream passage is desired, but the results of one study indicates that they can be effective for diverting fish to a bypass route.

EPRI has funded studies to evaluate the effectiveness of behavioral guidance systems at a number of sites throughout the United States. In addition, the results of many behavioral guidance studies funded by others are summarized in the two EPRI reviews. In the first EPRI review, the behavioral guidance systems identified as having the greatest potential included strobe lights, mercury lights and sound systems. Subsequent field and laboratory studies funded by EPRI have indicated that strobe lights have the potential for successfully guiding many species of fish. The results obtained with juvenile American shad at the York Haven hydro project have been particularly successful. The EPRI-funded studies have resulted in continuation of strobe light research at York Haven, and studies at other field sites are ongoing at this time.

Several studies have indicated that mercury lights may be effective in attracting certain species of fish to fish bypasses, although their application to date has been limited. EPRI-funded studies on sound systems (primarily the "hammer") were largely inconclusive. However, recent studies summarized in the second EPRI review have demonstrated the potential for using transducer systems are capable of transmitting a wide range of frequencies and sound levels.

The primary advantages of behavioral devices include low installation costs, minimal impact on project operation, and potentially lower impacts on fish than physical diversion systems. The latter factor may be particularly important for fragile species such as clupeids that are easily injured when passing through physical screening structures. Limited information on the effectiveness of behavioral devices in full-scale field applications remains the primary obstacle to widespread application. However, the successful results obtained at York Haven and in several other recent studies are likely to result in full-scale testing of behavioral guidance systems at additional sites in the near future.

DETAILED SUMMARY:
Review of fish protection technologies available, specifically high velocity screens, barrier nets, and behavioral guidance systems.

Lab or Field

Biological or Hydraulic

Biological

species and size of test fish

not applicable

hatchery or wild

not applicable

range of velocities tested

not applicable

water temperature and clarity

not applicable

results of test by species, velocity, screen porosity etc...

not applicable

Mechanical

screen mesh design and porosity

not applicable

screen length/exposure time

not applicable

screen angle

not applicable

seal durability

not applicable

screen design loading

not applicable

Bypass/Penstock

volume of bypass flow relative to screen

not applicable

maximum velocity of bypass flow

not applicable

bypass to screen approach velocity ratio

not applicable

Debris loading

cleaning frequency

does not apply

duration of cycle

does not apply

timing of cycle (season)

does not apply

factors affecting load (reservoir size, watershed characteristics, elevation)

does not apply

Other:

- Eicher Screen Technology:

screen angle

16.5° @ Puntledge
16° @ Elwha
19° @ T.W. Sullivan

screen material

wedge wire
profile bar material by Hendrick
v-wire by Johnson

bar width/spacing

T.W. Sullivan = 2 mm spacing and width w/ uniform 50% porosity
Elwha = 1.9 mm wide and 3.2 mm spacing w/ 63% and 32% porosity
Puntledge = 2 mm spacing and width w/ uniform 58.5% porosity

screen porosity

Elwha design indicates that a reduced porosity near bypass decreases velocity perpendicular to screen (V_Z)
Puntledge design indicates uniform porosity works the best (with uniform flows)

penstock velocity

5, 6, and 7.8 fps at the three facilities
maximum velocity perpendicular to the screen = 3.5 fps

bypass flow

bypass flows must be ≥ to avg penstock flows

backflushing

duration of backflushing can be reduced by using a hydraulic piston screen seals

J-seal material (2 - 3 inches wide)

- Modular Inclined Screen Technology (MIS)

  a list of 21 general design criteria for the MIS

  15 ft maximum approach area width due to structural constraints of the screen

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 32
Author: Bengeyfield, W.
Year: 1994
Title: Evaluation of the Eicher fish screen at Puntledge Diversion Dam in 1993
Institution: Prepared for British Columbia Hydro & Power Authority
City: Burnaby, British Columbia. Canada
Date: March 1994
Pages: 45
Abstract: Since 1952, several fish guidance techniques have been tested by government agencies and BC Hydro to solve the smolt mortality problem at Puntledge GS. The use of lights, underwater sound, curtains of air bubbles and hanging chains, electrical fields, louvers, and temporary screening have been unsatisfactory. The success of a permanent inclined screen inside of the penstock (the Eicher screen) at Elwha Dam, Washington, in 1990, caused BC Hydro to investigate and eventually install a similar screen at Puntledge Diversion Dam in spring 1993.

A biological evaluation was conducted over the period of May 24 to July 30, 1993. Primary objectives were to determine the rates of direct and latent mortality to juvenile salmonid migrants of wild and hatchery origin. Secondary objectives were to characterize the degree of scale loss associated with screen passage, to assess differential rates of injuries in daytime and darkness, and to determine the timing and abundance of wild coho and chinook salmon migrants in 1993.

BC Hydro constructed two inclined screens inside twin penstock pipes about 25 m downstream of the trash racks at Intakes 3 and 4. Only the fish screen at Intake 3 was evaluated in 1993; the screen for Intake 4 operated normally with bypass flows and fish discharging into the river. Fish entered Intake 3 through the trash racks, and were swept past the screen into a bypass pipe carrying about 25 cfs. This discharge entered the evaluation facility as an upward vertical jet in the energy dissipation chamber. As water spilled over an adjustable stoplog weir, fish were captured by three traps which collectively sampled 19% of the discharge. Fish were conveyed into the laboratory without direct handling for counting and analysis before being moved to four outdoor tanks used to hold fish for 96-h.

In addition to sampling wild coho and chinook smolts, experimental smolts from Puntledge hatchery were released at two locations: (1) downstream of the trash rack at Intake 3, to establish the rates of injuries during passage across the screen plus through the evaluation facility; and (2) in the dissipation chamber, to establish injury rates through the evaluation facility alone.

Direct mortality to 9758 wild coho and 1442 wild chinook smolts passing the screen were 0.05% and 0.14 respectively. Direct mortality to 155 hatchery coho was 0.65%, and to 244

hatchery chinook was 0.41%. Latent mortality after screen passage among 5296 wild coho held for 96-h was 0. 13%, and among 1377 wild chinook was 0.58%. Latent mortality to 154 hatchery coho was 3.25%, and to 237 hatchery chinook was 7.59%.

Gross total mortality was 0.18% for wild coho smolts and 0.72% for wild chinook smolts. Adjusted total mortalities to account for the temporary evaluation facility reduced the incidence for wild coho to 0.12% while wild chinook remained at 0.72%. Hatchery fish used in release experiments incurred higher overall mortality rates than the wild populations, likely as a result of infections by *Saprolegnia* (fungus) and PKD (proliferative kidney disease). Mortalities among wild fish migrating in daytime and dark periods were proportional to the numbers captured in those periods, suggesting that an ability to visually orient to the trash rack and screen did not improve survival.

The entrainment rate of fish passing to the turbine while the screens were opened for backwashing on 4-h cycles was calculated to be 1.25%. Based on a turbine mortality rate of 58%, the backwashing operation conferred an additional mortality component of 0.725% to all groups. Based on the range of run sizes estimated for coho smolts between 1989 and 1993, annual entrainment could range from 1358 to 1862 smolts, and annual turbine mortality would range from 788 to 1080 smolts, assuming that 58% of the entrained fish are killed during turbine passage.

Only wild fish were examined for scale loss. A higher proportion of sockeye smolts (20% of 10 fish) were categorized as descaled according to the Columbia River Scale Loss Protocol although their numbers were low. Of the major species, wild chinook smolts had a higher incidence of descaled fish (5-7% of 265 fish) than wild coho smolts (3.8% of 342 fish). The wild coho population exhibited an increase in scale loss after passage through the penstock system, but it was not possible to differentiate effects of the screen vs. the evaluation facility.

The 1993 coho smolt run size was estimated between 102,700 and 119,000 fish. This estimate does not include the early portion of the outmigration which spilled over the diversion dam prior to the study. The 1993 chinook smolt run was estimated between 15,200 and 17,600 fish through the end of July.

DETAILED SUMMARY:

Lab or Field
Field study
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - coho
    - chinook
    - sockeye
    - chum
    - steelhead

hatchery or wild

hatchery and wild coho and chinook
wild steelhead
wild sockeye
hatchery chum

range of velocities tested

facility design criteria = 1.83 m/s (6.0 fps)
sweeping velocity:normal velocity ratio = 3:1

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

mortality of fish passing through Eicher Screen

species	length (mm)	n	year	% dir. mort.	% 96 hr mort.	% total mort.
coho	84-135	9758	1993	0.05	0.13	0.18
coho	84-135	5184	1994	0.06	0.05	0.11
chinook	69-115	1442	1993	0.14	0.58	0.72
chinook	69-115	698	1994	0.00	0.19	0.19
sockeye	96-155	31	1993	0.00	4.17	4.17
sockeye	96-155	131	1994	1.53	2.17	3.70
trout	264-310	14	1993	0.00	0.00	0.00
chum	41-54	424	1994	0.94	2.60	3.54

fish classified as descaled (16% on one side or 40% on 2 of 5 zones)

species	n	year	% descaled	cntrl. scale loss (n)
coho	340	1993	3.8	1.6 (63)
coho	286	1994	4.4	
chinook	264	1993	5.3	4.0 (24)
chinook	181	1994	3.3	
sockeye	10	1993	20.0	
sockeye	64	1994	12.5	
steelhead	2	1993	0.0	
steelhead	6	1994	0.0	

Mechanical

screen mesh design and porosity

Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing

screen length/exposure time

12.8 m long (42 ft)

screen angle

16.5°

seal durability

did not report

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

3.2 m (10.5 ft) diameter penstock

0.61 m (2 ft) diameter bypass pipe discharging 0.71 m^3/s (25.1 cfs)

maximum velocity of bypass flow

design criteria = 2.44 m/s (8 fps)

bypass to screen approach velocity ratio

design criteria = 2.44 m/s (8 fps):1.83 m/s (6 fps)

Debris loading

cleaning frequency

4 hour cycle

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- results are presented as part of Smith (1997):
- entrainment of fish that pass during screen backwashing was computed at 1.25%
- recommendations included trash rack intake cleaning
- See Smith (1997) for detailed results of Puntledge Eicher screen study

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 33
Author: Bengeyfield, W.
Year: 1995
Title: Evaluation of the Eicher fish screen at Puntledge Diversion Dam year 2 (1994)
Institution: Prepared for British Columbia Hydro & Power Authority
City: Burnaby, British Columbia. Canada
Date: March 1995
Pages: 45
Abstract: This study evaluated fish passage at the second Eicher screen that was installed at Puntledge Diversion Dam in 1993. The study period had two segments: April 20 to July 31 and October 14 to December 12, 1994. The primary objectives were to determine the rates of direct and latent (96-h) mortality and the incidence of scale loss to wild juvenile salmonid populations moving downstream past Screen 2. Secondary objectives were to: (1) test survival of fish smaller than the design fish- a 37 mm chinook salmon fry; (2) conduct a salt water challenge experiment after screen passage; (3) conduct a preliminary mark-recapture experiment to assess the likelihood of differential entrainment at the two intakes; and (4) determine timing and estimate numbers of migrating fish in 1994.

The layout of facilities was similar to that of the 1993 study except that the bypass pipes were switched to enable assessment of fish passing Screen 2 while those passing Screen 1 were now discharged directly back to the river. Fish entered the intake, through the trash racks, and within 40 m downstream were swept past Screen 2 into a bypass pipe carrying -25 cfs. The bypass discharge entered the evaluation facility as an upward vertical jet in the energy dissipation chamber. As water spilled over an adjustable stoplog weir, fish were captured by three Wolf traps which collectively sampled 19% of the discharge. Fish were conveyed into the laboratory without direct handling for counting and analysis before being moved to four outdoor tanks used to hold fish for 96-h (latent mortality tests).

Wild coho and chinook smolts were the most numerous migrants, with much smaller catches of sockeye and steelhead smolts. Direct mortality to 5,184 wild coho and 698 wild chinook smolts passing the screen were 0.06% and 0.0%, respectively. Latent mortality after screen passage among 3,840 wild coho held for 96-h was 0.05%, and among 537 wild chinook was 0.19%. The rate of fish passing to the turbine while the screens were opened for backwashing on 4-h cycles had been calculated to be 1.25%. Based on a turbine mortality rate of 58%, the backwashing operation conferred an additional mortality component of 0.73% to all groups. Total mortalities were calculated by adding direct, latent, and backwashing components: coho smolts = 0.84%, chinook = 0.92%, sockeye = 4.43%, and steelhead = 0.73%.

Sockeye smolts (n=131) ranked highest in direct (1.53%) and latent (2.17%) categories as well as having the highest scores of average % scale loss per individual (7.7%) and % individual is classified as descaled (12.5%). Of the major species, wild chinook smolts had a

lower incidence of descaled fish (33%) than wild coho smolts (4.4%) after screen passage. These results were similar to background levels of descaling measured among fish angled from the forebay- 3.5% in 18 chinook and 4.2% in 63 coho smolts.

In the test using small fish, trap recovery of 424 of 1,985 hatchery chum salmon fry indicated a direct mortality rate of 0.9% and latent mortality of 2.6%. However, the video record showed that many of the released fish appeared to be impinged on the face of the screen and slid to the bypass entrance. Furthermore, 5 to 7 percent of the release may have been entrained through the screen.

Results of the 96-h salt water challenge experiments to coho and chinook smolts were inconclusive. In four of six trials, mortalities were higher in groups that entered 29 parts per thousand salt water directly after passage. However, in one trial for each species, there were 0 mortalities in the direct salt water group but mortalities did occur in groups that spent at least 24-h in fresh water. One chinook trial that resulted in 70% (7 of 10 fish) mortality for the 24-h fresh water/ 72-h salt water group may have been caused by toxic levels of aluminum from improper water storage.

A preliminary test of differential entrainment suggested that Intake 4 (Screen 2) passed 37% of the 1994

outmigration. Based on this proportion, the 1994 run sizes were estimated as follows: (1) coho between 71,900 and 88,700 fish in the spring study period, and 1,800 to 2,300 in the fall period; (2) chinook between 9,700 and 12,000 fish in spring, and 213 to 263 fish in fall. If Intake 3 entrained 63% of the annual run and not 50% as previously assumed, then the 1993 coho smolt run size, formerly estimated at 102,700 to 119,000 fish, would be reduced to between 81,500 and 94,400 fish. Similarly, the 1993 chinook run, previously estimated at 15,200 to 17,600 fish, was revised downward to between 12,000 and 14,000 fish.

DETAILED SUMMARY:

Lab or Field
Field study
Biological or Hydraulic
- **Biological**
  - **species and size of test fish**
    - coho
    - chinook
    - sockeye
    - chum
    - steelhead
  - **hatchery or wild**
    - hatchery and wild coho and chinook
    - wild steelhead
    - wild sockeye

hatchery chum

range of velocities tested

facility design criteria = 1.83 m/s (6.0 fps)

sweeping velocity:normal velocity ratio = 3:1

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

results of test by species, velocity, screen porosity etc...

mortality of fish passing through Eicher Screen

species	length (mm)	n	year	% dir. mort.	% 96 hr mort.	% total mort.
coho	84-135	9758	1993	0.05	0.13	0.18
coho	84-135	5184	1994	0.06	0.05	0.11
chinook	69-115	1442	1993	0.14	0.58	0.72
chinook	69-115	698	1994	0.00	0.19	0.19
sockeye	96-155	31	1993	0.00	4.17	4.17
sockeye	96-155	131	1994	1.53	2.17	3.70
trout	264-310	14	1993	0.00	0.00	0.00
chum	41-54	424	1994	0.94	2.60	3.54

fish classified as descaled (16% on one side or 40% on 2 of 5 zones)

species	n	year	% descaled	cntrl. scale loss (n)
coho	340	1993	3.8	1.6 (63)
coho	286	1994	4.4	
chinook	264	1993	5.3	4.0 (24)
chinook	181	1994	3.3	
sockeye	10	1993	20.0	
sockeye	64	1994	12.5	
steelhead	2	1993	0.0	
steelhead	6	1994	0.0	

Mechanical

screen mesh design and porosity

Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing

screen length/exposure time

12.8 m long (42 ft)

screen angle

16.5°

seal durability
did not report
screen design loading
did not report

Bypass/Penstock
volume of bypass flow relative to screen
3.2 m (10.5 ft) diameter penstock
0.61 m (2 ft) diameter bypass pipe discharging 0.71 m^3/s (25.1 cfs)
maximum velocity of bypass flow
design criteria = 2.44 m/s (8 fps)
bypass to screen approach velocity ratio
design criteria = 2.44 m/s (8 fps):1.83 m/s (6 fps)

Debris loading
cleaning frequency
4 hour cycle
duration of cycle
did not report
timing of cycle (season)
did not report
factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:
- results are presented as part of Smith (1997):
- sockeye smolts ranked highest in percent direct mortality, percent latent mortality, avg scale loss, and percent descaled.
- wild coho and chinook may have suffered increased scale loss the result of debris on trash racks
- the Eicher screen has proven to be a very good solution to the turbine mortality problems in the Puntledge River
- as in 1993, debris lodged in the trash racks may have been the cause of some descaling
- See Smith (1997) for detailed results of Puntledge Eicher screen study

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Technical Report
Record Number: 34
Author: Matthews, J.G., and G.J. Birch
Year: 1991
Title: Puntledge diversion Dam permanent fish screen overview study
Institution: British Columbia Hydro & Power Authority
City: Burnaby, British Columbia, Canada
Pages: 72
Abstract: Before dams were built on the Puntledge River, it supported one of the largest sport and commercial fisheries on the east coast of Vancouver Island. Although fish ladders were built at both Puntledge and Comox dams, these and other mitigation measures have been only partially successful in restoring the fishery. The major remaining problem is the passage of juvenile migrants through the turbine at Puntledge Generating Station. At least 60% of the juvenile migrants, which can be as small as 37 mm long, are killed when they pass through the generating system. B.C. Hydro has recognized the loss of fish as an unacceptable environmental impact resulting from its operations and is committed to reducing that impact.

Closure of the generating plant for the migration period is the most readily available solution to the problem but the lost revenue has a present value of about $25,000,000. Screening the juvenile migrants from the power flow at the penstock intake so that they bypass the turbine is an alternative solution, which would cost about $4 million.

Rotating drum screens, vertical screens and screens inside penstocks were examined. Penstock screens, which would be at a 16.5° angle to the flow and would have a central pivot for periodic reverse flushing, were found to be the most economical at a cost of about $4 million. Although penstock screens are a relatively new technology, it is recommended that they be adopted for the next stage of study. Hydraulic model studies are recommended.

Construction of the screen to catch the spring migration in 1993 will require a concentrated effort on design during the 1991-92 winter and a commitment to final design and construction by 28 February 1992.

<u>DETAILED SUMMARY</u>:

Lab or Field
A detailed history of the Puntledge River fishery, including causes for the decline of one of the most economically important anadromous fisheries on Vancouver Island. A brief description of diversion alternatives along with design criteria is also furnished in the report.

Biological or Hydraulic
Biological
species and size of test fish

not applicable

hatchery or wild

not applicable

range of velocities tested

not applicable

water temperature and clarity

not applicable

results of test by species, velocity, screen porosity etc...

not applicable

Mechanical

screen mesh design and porosity

not applicable

screen length/exposure time

not applicable

screen angle

not applicable

seal durability

not applicable

screen design loading

not applicable

Bypass/Penstock

volume of bypass flow relative to screen

not applicable

maximum velocity of bypass flow

not applicable

bypass to screen approach velocity ratio

not applicable

Debris loading

cleaning frequency

not applicable

duration of cycle

not applicable

timing of cycle (season)

not applicable

factors affecting load (reservoir size, watershed characteristics, elevation)

not applicable

Other:

- Design criteria for each alternative consisted of:
  - fish species and size
  - design criteria
    - flow and velocity criteria
    - screen mesh opening, screen area, screen porosity
    - bypass entrance, conduit, and outfall criteria
- Recommendations were made to use the penstock screen (Eicher) for preliminary design because the screen was more economical than vertical or drum screens

U.S. COE HIGH VOLUME DEWATERING
Literature Search

Reference Type: Personal Comm.
Record Number: 35
Author: Katopodis, C.
Year: 11 August, 1997
Title: Adjunct Professor, Civil & Environmental Engineering, University of Alberta, Civil & Geological Engineering, University of Manitoba, Biology, University of Waterloo.
Publisher: University of Alberta
Date: 11 August, 1997
Type: fax message
Abstract: The key to our testing is our new flume (IMEF or Ichthyohydraulics Mobile Experimental'; Flume) which allows for testing prototype screens with the species and sizes of fish desired. The IMEF consists of five detachable components for ease of transportation. Two components, each almost 10 m in length, make up the rectangular testing channel. The inlet tank, the outlet tank and the pump skid are the other three components. The flume testing section located between the tanks, is 19.5 m (64 ft) in length, 1.0 m (3.3 ft) in width and 1.2 m (4 ft) in depth. The inlet and outlet tanks are 2.4 m x 2.4 m (8 ft x 8 ft) in plan and each contains a fish holding compartment. This allows fish to be introduced and tested for either upstream or downstream passage. A variable speed diesel powered pump capable of circulating up to 650 L/s (Litres per second) of water between the two tanks control the flume discharge. A second pump can be added to double the discharge capacity for the IMEF. Head driven flow controlled by a sluice gate will generate high uniform velocities and gravity flow will produce low velocities. Flow straighteners and stilling devices will achieve uniform flow conditions with reduced turbulence and surface waves. The one side of the flume is constructed from clear lexan to allow visual observations.

<u>DETAILED SUMMARY</u>:

Lab or Field
Near field, using the Ichthyohydraulics Mobile Experimental Flume (IMEF) to test prototype screens. Fish tests will determine the best screen design criteria. Tests are planned for 1997 and 1998.

Biological or Hydraulic
Biological
species and size of test fish
rainbow trout
60, 90, 120 mm
hatchery or wild
hatchery

range of velocities tested

0.5 m/s (1.64 fps)
1.0 m/s (3.38 fps)
2.0 m/s (6.56 fps)

water temperature and clarity
did not report

results of test by species, velocity, screen porosity etc...
tests have not been conducted at this time

Mechanical

screen mesh design and porosity
did not report

screen length/exposure time
did not report

screen angle
10 - 20°

seal durability
did not report

screen design loading
did not report

Bypass/Penstock

volume of bypass flow relative to screen
did not report

maximum velocity of bypass flow
did not report

bypass to screen approach velocity ratio
did not report

Debris loading

cleaning frequency
did not report

duration of cycle
did not report

timing of cycle (season)
did not report

factors affecting load (reservoir size, watershed characteristics, elevation)
did not report

Other:

- Results will be supplied upon completion of the project.

U.S. COE HIGH VOLUME DEWATERING

Literature Search

Reference Type: Conference Proceedings
Record Number: 36
Author: Knight, J.W., and D.J. Salisbury
Year: 1997
Title: British Columbia Hydro's commitment to the environmental movement: Puntledge River Hydro Intake Facility.
Conference Name: Waterpower '97
Editor: D.J. Mahoney
Conference Location: Atlanta, Georgia
Volume: 3
Pages: 2231-2250
Abstract: A review of British Columbia (B.C.) Hydro's Puntledge River Dam Intake Facility conducted to examine the performance of a fish bypass system for downstream migrating juvenile salmon (smolts). The scope of the paper deals with the operation of fish screens for descending smolts and the effectiveness of the screens for the safe passage of these fish at the downstream components of the Puntledge River Hydro Intake Facility. Future application of the fish screens was also reviewed.

It was found that the Puntledge River Hydro Intake Facility reflects B.C. Hydro's commitment to environmental change. The Puntledge River Hydro project was first developed in 1913 for the purpose of supplying power to local coal mines, and in 1957 was expanded to increase penstock flows. This led to increased difficulties in implementing anadromous fish protection measures, and a decision was made to close the river above the dam to fish passage. The main problem faced by smolts was increased entrainment into the peak tube where they had to pass through the turbines. The resulting combined mortality was as high as 60% for chinook salmon *(Oncorhynchus tshawytscha),* coho salmon *(Ocorhynchus kisutch)* and steelhead trout *(Oncorhynchus mykiss).* In 1988 a decision was made to solve the problem of downstream passage protection and by 1989 several types of behavioral and physical fish diversion devices were installed. The initial results were not positive as the diversion rate was only 8.6% for smolts. In 1990 a fish guidance system was tested and increased diversion to 11.1%. During 1991 and 1992 a barrier net was tested and diverted 99% of the coho smolts away from the penstock/turbine, but the barrier net proved to be impractical because it would not function during uncontrolled freshet flows. A device called the Eicher screen was selected as a permanent solution to turbine mortality of the smolts. In 1993 and 1994 the Eicher screens were found to yield 99.8% efficiency for diverting coho and chinook smolts safely away from the penstock intake.

DETAILED SUMMARY:

Lab or Field
Review of the biological tests reported by Smith (1997) which were conducted in 1993 and 1994.
Biological or Hydraulic
Biological

species and size of test fish

coho
chinook
sockeye
chum
steelhead

hatchery or wild

hatchery and wild coho and chinook
wild steelhead
wild sockeye
hatchery chum

range of velocities tested

facility design criteria = 1.83 m/s (6.0 fps)
sweeping velocity:normal velocity ratio = 3:1

water temperature and clarity

did not address

results of test by species, velocity, screen porosity etc...

24 May - 30 July, 1993

	direct mortality	latent mortality	backwash mortality	total mortality	scale loss
juv. coho	0.05	0.13	0.73	0.91	4.6
juv. chinook	0.14	0.58	0.73	1.45	6.1

20 April - 12 July, 1994

	direct mortality	latent mortality	backwash mortality	total mortality	scale loss
juv. coho	0.06	0.05	0.73	0.84	6.1
juv. chinook	0.00	0.19	0.73	0.92	5.6

Mechanical

screen mesh design and porosity

Johnson stainless steel wedge-wire with 58% uniform porosity and 2.5 mm bar spacing

screen length/exposure time

12.8 m long (42 ft)

screen angle

16.5°

seal durability

rubber seals have remained intact and functional over 5 years

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

3.2 m (10.5 ft) diameter penstock
0.61 m (2 ft) diameter bypass pipe discharging 0.71 m^3/s (25.1 cfs)

maximum velocity of bypass flow
design criteria = 2.44 m/s (8 fps)

bypass to screen approach velocity ratio
design criteria = 2.44 m/s (8 fps):1.83 m/s (6 fps)

Debris loading

cleaning frequency
4 hour cycle in 1993

a pressure sensor was installed in 1994 to cycle the screen when pressure

duration of cycle
did not report

timing of cycle (season)
did not report

factors affecting load (reservoir size, watershed characteristics, elevation)
small debris (< 2 in) may enter the penstock
most of debris is captured via a log boom and 2 inch aperture trash rack
in 1996, cleaning systems were unable to manage debris on 2 occasions, causing the penstock intake gate closure

Other:

- numerous recommendations were made before the start of the 1994 field season: cleaning the trash rack more often; cleaning the plexiglas in the penstock; and raising the jump screen on the collection tank to prevent fish from escaping
- the 1993 test involved hatchery and wild fish, testing the intake #3 in the southern penstock
- the 1994 test involved only wild coho and chinook juveniles, testing the intake #4 in the northern penstock
- bypass rates for smolts at the Puntledge Facility using four different methods (year tested):
  behavioral device = 8.6% (1989)
  electrical field = 11.1% (1990)
  barrier net = > 99% (1992-1993)
  Eicher screen = 99.8% (1993)

Reference Type: Conference Proceedings
Record Number: 37
Author: Taft, E.P., F.C. Winchell, S.V. Amaral, T.C. Cook, A.W. Plizga, E.M. Paolini, and C.W. Sullivan
Year: 1997
Title: Field evaluations of the new modular inclined fish diversion screen.
Conference Name: Waterpower '97
Editor: D.J. Mahoney
Conference Location: Atlanta, Georgia
Volume: 1
Pages: 665-671
Abstract: A new type of fish diversion screen, known as the Modular Inclined Screen (MIS), is designed to provide fish protection at any type of water intake. Because the screen operates at water velocities of up to about 10 ft/sec (3 m/s) in the approach channel, the MIS is more compact and cost-effective than existing low-velocity screens. A biological evaluation of the MIS was conducted in the laboratory with juveniles of eleven fish species. Net passage survival typically exceeded 99% at velocities up to 6 ft/sec (1.8 m/s) for most species, and exceeded 99% overall (all velocities combined) for four species. On the basis of these results, a prototype MIS was constructed and evaluated at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project on the Hudson River. The prototype screen has a flow capacity of 150 cfs (4.2 ml/s) at an approach velocity of 7.5 ft/sec (2-3 m/s). Field evaluation of the MIS in 1995 and 1996 confirmed high rates of diversion and survival of juvenile rainbow trout, golden shiners, largemouth bass and yellow perch, although lower survival was observed for the relatively fragile blueback herring. This paper presents the results of both the 1995 and 1996 field evaluation programs.

<u>DETAILED SUMMARY</u>:

Lab or Field
Field and laboratory test results of the modular inclined screen (MIS).
Biological or Hydraulic
  Biological
    species and size of test fish
    rainbow trout juveniles (94.7 mm) were the only cold water species used in field tests, along with 5 warm water species
      laboratory tests used:
        Atlantic salmon (169 mm)
        coho (49 mm)
        rainbow trout (66 mm)
        chinook salmon (53 mm)
        brown trout (60 mm)
        rainbow trout (48 mm)

    hatchery or wild
      did not report

range of velocities tested

0.61 m/s (2.0 fps); 1.22 m/s (4.0 fps); 1.83 m/s (6.0 fps); 2.44 (8.0 fps); 3.05 m/s (10.0 fps)

water temperature and clarity

did not report

results of test by species, velocity, screen porosity etc...

Results of laboratory tests in 1992 and 1993.
net passage survival (%)

species	2 fps	4 fps	6 fps	8 fps	10 fps	combined
Atl. salmon	100	100	100	100	100	100
coho	100	100	100	99.0	99.6	99.7
rainbow (66 mm)	100	99.2	100	98.9	97.4	99.1
chinook	100	100	99.3	98	97.2	98.9
brown trout	93.6	100	99.8	98.8	99.1	98.3
rainbow (48 mm)	92.6	100	100	95.2	96.8	96.9

Results of field tests in 1995 and 1996
net passage survival (%)

species	2 fps	4 fps	6 fps	8 fps	10 fps	combined
rainbow	-	100	100	99.3	-	99.8

Mechanical

screen mesh design and porosity

50% porosity Hendrick profile bar with 2 mm spacing

screen length/exposure time

4.9 m long (16 ft) X 1.5 m wide (5 ft)

screen angle

15°

seal durability

seals were adequate to prevent fish passage and allow free movement of the screen during back washing

screen design loading

did not report

Bypass/Penstock

volume of bypass flow relative to screen

0.3 m (1 ft) entrance to bypass

maximum velocity of bypass flow

did not report

bypass to screen approach velocity ratio

did not report

Debris loading

cleaning frequency

screen was back washed at the end of each test, with total removal of debris

duration of cycle

did not report

timing of cycle (season)

did not report

factors affecting load (reservoir size, watershed characteristics, elevation)

did not report

Other:

- full scale applications of the MIS is being sought at an existing intake structure